Plasma Science

From Fundamental Research to Technological Applications

Panel on Opportunities in Plasma Science and Technology

Plasma Science Committee
Board on Physics and Astronomy
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

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Cover: A snapshot of the electron density distribution in a magnetized, pure-electron plasma. These plasmas are nearly ideal, inviscid, two-dimensional fluids and are being used to study the relaxation and self-organization of fluid turbulence (see Plate 2 for details). (Courtesy of C.F. Driscoll, University of California, San Diego.)

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Preface

In the mid-1980s, the plasma physics volume of the series *Physics Through the 1990s* (National Research Council, National Academy Press, Washington, D.C., 1986) signaled problems for plasma science in the United States, particularly with regard to the basic aspects of the science. In the years that followed, there developed a widespread feeling in the plasma science community that something systematic needed to be done to address these issues. Out of this concern, the Plasma Science Committee of the Board on Physics and Astronomy was created in 1988. Following its establishment, plans were begun to undertake this study. With funding from the National Science Foundation, the Department of Energy, and the Office of Naval Research, the Panel on Opportunities in Plasma Science and Technology was appointed in May 1992, and the study began.

Approximately half of the 13-member panel consisted of experts in the many facets of plasma science considered in this report and half of scientists outside the field, with one of the co-chairs selected as a person with experience in science policy. Three of the members are from industry; one is from a government laboratory and one from an independent research society; and the remaining eight are from academe.

The task statement to the panel requested that this study examine virtually all aspects of plasma science and technology in the United States, assess the health of basic plasma science as a research enterprise, and identify and address key issues in the field. Specifically, the panel was charged with the task of conducting an assessment of plasma science that included beams, accelerators, and coherent radiation sources; single-species plasmas and atomic traps; basic plasma science in magnetic confinement and inertial fusion devices; space plasma physics; astrophysics; low-temperature plasmas; and theoretical and computational plasma science. It was directed to address the following:

1. Assess the health of basic plasma science in the United States as a research enterprise: (a) Identify and describe selected scientific opportunities. (b) Identify and describe selected technological opportunities. (c) Assess and prioritize new opportunities for research using the criteria of intellectual challenge, prospects for illumination of classic research questions, connection with other fields of science, and potential for applications. (d) Assess applications using the criteria of potential for contributing to industrial competitiveness, national defense, human health, and other aspects of human welfare.
2. Identify and address the issues in the field, including the following: (a) Evaluate the quality and size of the educational programs in plasma science in light of the nation's future needs. (b) Assess the institutional infrastructure in which plasma science is conducted, and identify changes that would improve the research and educational effort. (c) Characterize the basic experimental facilities needed to increase scientific productivity. (d) Develop a research strategy that is responsive to the issues. (e) Compare the U.S. program with those of Japan and Western Europe, and identify opportunities for international cooperation. (f) Identify the interactions and synergism with other areas of physics, chemistry, mathematics, and astronomy. (g) Assess the linkage of theory and experiment. (h) Assess manpower requirements and the prospects for meeting them. (i) Identify the users of plasma science and their needs.
3. Make recommendations to federal agencies and to the community that address these issues.

During the course of the study, the panel held three two-day meetings and two lengthy teleconferences. As part of the process, the panel took steps to solicit input from the plasma science community. Letters were sent to 200 scientists and engineers, requesting their input on the issues raised in the charge to the panel. This list was selected from the list of Fellows of the Plasma Physics Division of the American Physical Society (90), and it also included others suggested by members of the panel (65) and by grant officers involved in funding plasma science (45). The letters went to university faculty and staff (90), industrial scientists (25), staff at national laboratories (50), and others (5). A separate, more specialized survey was sent to 33 experimentalists engaged in basic plasma physics research. Input was also solicited by announcements of the panel's work that appeared in the newsletters of the American Geophysical Union, the American Physical Society, the Plasma Physics Division of the American Physical Society, the Committee on Plasma Science of the Institute of Electrical and Electronics Engineers (IEEE), and the University Fusion Associates. Town meetings were held at American Physical Society Plasma Physics Division meetings and the Gaseous Electronics Conference. There is general agreement from these sources on the themes expressed in this report: There is concern about the decline in basic plasma science, particularly in the area of basic plasma experimentation and other small-scale research efforts, and basic plasma science is perceived to lack a "home" in the federal agencies.

Also during the course of the study, the panel heard presentations from grant officers involved in funding plasma science from the Air Force Office of Scientific Research, the Advanced Research Projects Agency, the Department of Energy, the National Aeronautics and Space Administration, the National Science Foundation, and the Office of Naval Research.

The task statement requested that the panel assess specific areas of plasma science, such as beams, accelerators, and coherent radiation sources (called *topical areas* in the report), and *broad areas of plasma science*, including fundamental plasma experiments, theoretical and computational plasma physics, and education in plasma science. At the first meeting of the panel, these areas were renamed slightly and the topical area of low-temperature plasmas was added, since it had been omitted from the task statement through an oversight. The resulting seven topical areas are assessed in Part II of the report, and the three broad areas of plasma science are assessed in Part III. Part IV consists of some concluding remarks.

During the course of the study, the panel had numerous discussions about the desirability of establishing organizational units specifically devoted to plasma science in the relevant federal agencies. Many members of the plasma science community who were consulted strongly advocated the establishment of such homes, believing that they are needed if basic plasma science is to be given the focused attention and increased support that the panel recommends. While this subject is beyond the scope of the panel's work, the panel suggests that the federal government might give this issue further consideration.

Acknowledgments

In preparing this report, the Panel on Opportunities in Plasma Science and Technology has benefited greatly from the assistance of many members of the plasma science community. We are particularly indebted to the former chairs of the Plasma Science Committee of the Board on Physics and Astronomy, C.F. Kennel and F.W. Perkins, and the present chair, Ravi Sudan, for their advice and help. The other members of the Plasma Science Committee also provided valuable advice during the course of the study.

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PART II

TOPICAL AREAS

Plasma Science

From Fundamental Research to Technological Applications

Executive Summary

Plasma science is the study of the ionized states of matter. Most of the observable matter in the universe is in the plasma state. Plasma science includes plasma physics but aims to describe a much wider class of phenomena in which, for example, atomic and molecular excitation and ionization processes and chemical reactions can play significant roles. The intellectual challenge in plasma science is to develop principles for understanding the complex macroscopic behavior of plasmas, given the known principles that govern their microscopic behavior.

Plasmas of interest range over tens of orders of magnitude in density and temperature—from the tenuous plasmas of interstellar space to the ultradense plasmas created in inertial confinement fusion, and from the cool, chemical plasmas used in the plasma processing of semiconductors to the thermonuclear plasmas created in magnetic confinement fusion devices. A healthy plasma science enterprise can be expected to make many important contributions to our society for the foreseeable future. The purpose of this report is to provide guidance regarding the ways in which plasma science can contribute to society and to recommend actions that will optimize these contributions.

FINDINGS

1. Plasma science impacts daily life in many significant ways. It plays an important role in plasma processing, the sterilization of medical products, lighting, and lasers. Plasma science is central to the development of fusion as an

energy source, high-power radiation sources, intense particle beams, and many aspects of space science.

2. Plasma science is a fundamental scientific discipline, similar, for example, to condensed-matter physics. This fact is apparent when one considers the commonality of the intellectual problems in plasma science that span the wide range of applications to science and technology. Despite its fundamental character, plasma science is frequently viewed in the academic community as an interdisciplinary enterprise focused on a large collection of applications. Experiment, theory, and computation are all critical components of modern plasma science.

3. While the applications of plasma science have been supported by the federal government, no agency has assumed responsibility for basic research in plasma science. In general, there is a lack of coordination of plasma science research among the federal agencies.

4. As the development of plasma applications has progressed, small-scale research efforts have declined, particularly in the area of basic plasma experiments. This decline has led to a significant backlog of important scientific opportunities. This core activity in fundamental plasma science, carried out by small groups and funded by principal-investigator grants, is dangerously small, considering its importance to the national effort in fusion energy and other applied programs.

5. Plasma scientists in academic institutions are less likely to be in tenure-track positions than are other physicists, and courses in plasma science are currently unavailable at many educational institutions.

CONCLUSIONS

1. Plasma science can have a significant impact on many disciplines and technologies, including those directly linked to industrial growth. To properly pursue the potential offered by plasma science, the United States must create and maintain a coherent and coordinated program of research and technological development in plasma science.

2. Recognition as a distinct discipline in educational and research institutions will be crucial to the healthy development of plasma science.

3. There is no effective structure in place to develop the basic science that underlies the many applications of plasmas, and if the present trend continues, plasma science education and basic plasma science research are likely to decrease both in quality and quantity. If nothing is done by the federal government, it is likely that research in basic plasma science will cease to exist, and progress in the applications that depend on it will eventually halt.

4. The future health of plasma science, and hence its ability to contribute to the nation's technological development, hinges on the revitalization of basic plasma science and, in particular, on the revitalization of small-scale basic plas-

ma experiments. With regard to theory and modeling, although the current programs have been successful, there is a need for individual-investigator-led research on questions fundamental to basic plasma science.

5. Coordination of research efforts is vital, to make the most effective use of resources by maintaining complementary programs and to ensure that all critical problems are addressed.

6. Because of the commonality underlying all areas of plasma science, renewed emphasis on basic plasma science will benefit all areas. Therefore, it is appropriate that redistribution of funding to support basic plasma science come from all areas of plasma science.

RECOMMENDATIONS

1. To reinvigorate basic plasma science in the most efficient and cost-effective way, emphasis should be placed on university-scale research programs.

2. To ensure the continued availability of the basic knowledge that is needed for the development of applications, the National Science Foundation should provide increased support for basic plasma science.

3. To aid the development of fusion and other energy-related programs now supported by the Department of Energy, the Office of Basic Energy Sciences, with the cooperation of the Office of Fusion Energy, should provide increased support for basic experimental plasma science. Such emphasis would leverage the DOE's present investment in plasma science and would strengthen investigations in other energy-related areas of plasma science and technology.

4. Approximately $15 million per year for university-scale experiments should be provided, and continued in future years, to effectively redress the current lack of support for fundamental plasma science, which is a central concern of this report. Furthermore, individual-investigator and small-group research, including theory and modeling as well as experiments, needs special help, and small amounts of funding could be life-saving. Funding for these activities should come from existing programs that depend on plasma science. A reassessment of the relative allocation of funds between larger, focused research programs and individual-investigator and small-group activities should be undertaken.

5. The agencies supporting plasma science should cooperate to coordinate plasma science policy and funding.

6. Members of the plasma community in industry and academe should work aggressively for tenure-track recognition of plasma science as an academic discipline, and work with university faculty and administrators to provide courses in basic plasma science at the senior undergraduate level.

Additional recommendations regarding specific areas of plasma science are made in the main text of the report.