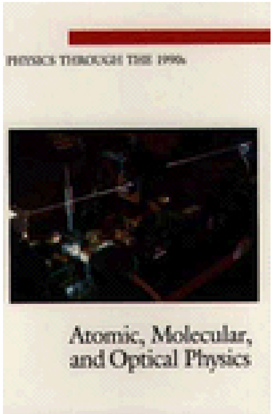

Atomic, Molecular, and Optical Physics

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PHYSICS THROUGH THE 1990s

Atomic, Molecular, and Optical Physics

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and Optical Physics
Physics Survey Committee
Board on Physics and Astronomy
Commission on Physical Sciences,
Mathematics, and Resources
National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

This report was prepared by the Panel on Atomic, Molecular, and Optical (AMO) Physics of the Physics Survey Committee in response to its charge to describe the field, to characterize the recent advances, and to identify the current frontiers of research. In carrying out this task, we were helped immeasurably by the members of the AMO community and others whose names appear on the following pages. We thank all of them for their contributions.

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This report was reviewed by the Committee on Atomic and Molec ular Science, National Research Council, whose members are F. M. Pipkin, *Chairman*, L. Armstrong, Jr., R. S. Berry, R. Bersohn, J. L. Dehmer, G. H. Dunn, D. E. Golden, G. S. Hurst, H. P. Kelly, K. Kirby, D. Kleppner, J. Macek, G. A. Martin, C. B. Moore, J. T. Moseley, F. Richard, A. Temkin, N. H. Tolk, J. C. Weisheit, and R. C. Woods; D. C. Shapero, *Staff Director*.

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Contents

Summary

THE NATURE OF THE FIELD

The goals of atomic, molecular, and optical physics (AMO physics) are to elucidate the fundamental laws of physics, to understand the structure of matter and how matter evolves at the atomic and molecular levels, to understand light in all its manifestations, and to create new techniques and devices. AMO physics provides theoretical and experimental methods and essential data to neighboring areas of science such as chemistry, astrophysics, condensed-matter physics, plasma physics, surface science, biology, and medicine. It contributes to the national security system and to the nation's programs in fusion, directed energy, and materials research. Lasers and advanced technologies such as optical processing and laser isotope separation have been made possible by discoveries in AMO physics, and the research underlies new industries such as fiber-optics communications and laser-assisted manufacturing. These developments are expected to help the nation to maintain its industrial competitiveness and its military strength in the years to come.

EDUCATIONAL ROLE

AMO physics plays an important role in the education of scientists in the United States at both the undergraduate and graduate levels.

University-based AMO research prepares students for careers in basic and applied science in industry, in national laboratories, and in universities. Approximately 140 Ph.D. degrees are awarded each year in AMO physics.

CONTRIBUTIONS TO NATIONAL PROGRAMS

AMO physics contributes broadly to the nation's programs in energy. Experimental and theoretical data from AMO laboratories are needed for fusion research with magnetic or inertial confinement. Spectroscopy and laser scattering are important diagnostic techniques for plasma fusion devices. Inertial-confinement experiments employ charged-particle devices and high-power lasers whose origins lie in AMO research. Using methods from modern optics, the chemistry of combustion can be studied in an engine as it runs, leading to improved efficiency of aircrafts, ships, and automobiles.

Basic research in AMO physics has revolutionized important areas of military technology. Atomic clocks and laser gyroscopes are central to modern navigation and global positioning systems; fiber-optics communication is widely used in ships, tanks, and planes. Data on atomic and molecular processes from AMO laboratories are vital to the understanding of atmospheric and meteorological phenomena that affect military scenarios. Lasers are used for range finding, guidance, optical radar, and numerous other applications; high-power lasers are being employed in new classes of countermeasures and directed energy weapons systems.

AMO research also contributes broadly to the nation's environmental program. Atomic and molecular data from AMO laboratories are crucial to understanding the chemistry of the atmosphere. Remote-sensing methods employing lasers and laser spectroscopy permit pollutants to be monitored at long distances. Much of our understanding of the effect of ionizing radiation on biological systems is based on data and theoretical research from AMO physics.

RECENT ADVANCES IN BASIC ATOMIC, MOLECULAR, AND OPTICAL SCIENCE

AMO physics encompasses broad areas of theoretical and experimental research on matter at the atomic and molecular level and on light. A few of the recent advances in atomic physics include optical spectroscopy of exotic atoms, new tests of quantum electrodynamics through ultraprecise measurements on individual trapped electrons and positrons, the production of very slow, highly charged ions, the prediction and study of spontaneous electron-positron formation in high nuclear fields, and the first direct measurement of dielectronic recombination. In molecular physics the advances include the development of general techniques for studying molecular ions. the creation of clusters (small groups of isolated molecules), surface scattering with supersonic molecular beams, and the discovery of energy localization in polyatomic molecules. Advances in optics include the first direct measurement of the frequency of an optical transition, the development of ultraprecise optical spectroscopy and ultrasensitive detection of atoms and molecules, laser cooling of ions and atoms, the coherent generation of far-ultraviolet light, optical bistability, and the creation of numerous new types of lasers and nonlinear optical techniques. These discoveries and numerous theoretical advances, including new approaches made possible by computers, have combined to make the past decade of AMO physics a period of substantial scientific progress and unprecedented productivity.

RESEARCH OPPORTUNITIES

The field of AMO physics is moving forward rapidly in wide areas of research on the structure and dynamics of atoms and molecules, the control and generation of light, and the fundamental laws of physics. From among the many activities in AMO physics, the Panel has identified a series of topics that hold promise for rapid advance and high scientific reward. These topics form the basis of a Program of Research Initiatives that is described in detail in the report. The initiative in atomic physics includes tests of fundamental physical laws, the development of high-precision techniques, and research on the many-electron problem and on the dynamics of atomic collisions. In molecular physics the research is centered on understanding the motion of electrons and nuclei in molecular fields and the possibility of controlling the exchange of energy and particles during molecular collisions. The initiative in optics includes the development of coherent light sources from the infrared to the x-ray regions, research on new methods of spectroscopy, and quantum optics.

This program is intended to advance our knowledge of basic AMO science, assure that the field can continue to provide essential data and new techniques for the other sciences, and allow AMO physics to continue its contributions to vital national programs and industry. The program is needed to provide the research environment that is essential