PHYSICS THROUGH THE 1990s

Nuclear Physics

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

NATIONAL ACADEMY PRESS 2101 Constitution Avenue, NW Washington, DC 20418

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The Board on Physics and Astronomy is pleased to acknowledge generous support for the Physics Survey from the Department of Energy, the National Science Foundation, the Department of Defense, the National Aeronautics and Space Administration, the Department of Commerce, the American Physical Society, Coherent (Laser Products Division), General Electric Company, General Motors Foundation, and International Business Machines Corporation.

Library of Congress Cataloging in Publication Data
Main entry under title:

Nuclear physics.

(Physics through the 1990s)
Bibliography: p.
Includes index.
1. Nuclear physics. 2. Nuclear physics—Research—United States. 3. National Research Council (U.S.). Nuclear Physics Panel. I. National Research Council (U.S.). Nuclear Physics Panel. II. Series.
QC776.P59 1985 539.7 85-10584
ISBN 0-309-03547-3

Printed in the United States of America

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Preface

This volume is the report of the Panel on Nuclear Physics of the Physics Survey Committee, established by the National Research Council in 1983. The report presents many of the major advances in nuclear physics during the past decade, sketches the impacts of nuclear physics on other sciences and on society, and describes the current frontiers of the field. It concludes with a chapter on the recommended priorities for this discipline.

The Panel on Nuclear Physics developed this report through its meetings in May 1983 and January 1984 and through extensive correspondence. We also joined with the Nuclear Science Advisory Committee (NSAC) of the Department of Energy and the National Science Foundation during its week-long Workshop in July 1983, when the major draft of its 1983 Long Range Plan was formulated. Appendix B lists those who attended the Workshop, which included broad participation beyond the members of NSAC or our Panel.

Most of the comments from 11 reviewers (see Appendix B), chosen to provide a representative viewpoint from the nuclear-science community, were incorporated into the manuscript, which was submitted to the National Research Council in May 1984 for further review. Additional comments were subsequently incorporated, and the final manuscript was submitted in August 1984.

Clearly, a comprehensive coverage of the field of nuclear physics would be impossible in a report of this size. Of necessity, only an overview of selected topics can be given, and the Panel has attempted to maintain a reasonable balance throughout. Although no explicit reference to nuclear chemistry per se is made in this report, we wish to note that nuclear chemists and nuclear physicists are working toward the same goal of understanding the nucleus. They thus have many interests in common and share the same experimental facilities.

The Panel wishes to thank the reviewers as well as the members of the Physics Survey Committee, the Board on Physics and Astronomy of the National Research Council, and a number of other individuals for their help in this task. We wish particularly to thank Fred Raab for his outstanding and invaluable assistance in the technical rewriting and editing of this report.

Contents

Executive Summary

NUCLEAR PHYSICS TODAY

Nuclear physics deals with the properties of atomic nuclei, their structure and interactions, and the laws governing the forces between their constituents. The interactions in nuclei have their roots in the interactions of elementary particles, the quarks and gluons that together constitute nuclear matter. But additional dynamical forces, long known to exist in nuclei, cannot be understood with elementary particles alone, just as new cooperative interactions, not recognizable in nuclei or atoms, are known to exist in macroscopic materials.

The basic questions facing nuclear physics today span a broad range, including strong and electroweak interactions, and cover the properties of the physical world from the microscopic scale of nuclear forces to the large-scale structure of the universe. Nuclear physics deals with many-body aspects of the strong interaction. It also deals with tests of fundamental theories and symmetries. Furthermore, nuclear physics plays an important role in the fields of astrophysics and cosmology.

Our understanding of nuclear structure and nuclear dynamics continues to evolve. New simple modes of excitation have emerged, new symmetries are appearing, and some completely new phenomena are being discovered.

In the 1970s, for example, several new modes of vibration of nuclei were discovered, using the technique of inelastic scattering of charged particles from target nuclei. One of these vibrations, the giant monopole, is particularly significant because of its direct relation to the heretofore unmeasured compressibility of nuclear matter. In similar studies using pions as projectiles, important information on the relative roles of protons and neutrons in nuclear vibrations has been gained, as well as that of nucleon excited states called deltas.

The use of high-energy electron scattering from nuclei has revealed unprecedented levels of detail of nuclear structure, in terms not only of the nucleons but also of the mesons present in nuclei and, to a rudimentary degree, of the quarks that compose all of these particles. Such studies represent one of the major frontiers of nuclear physics today.

At the opposite extreme of projectile size, heavy ions have come into increasingly widespread use, particularly as versatile probes of nuclear dynamics. Their massive impact on target nuclei can cause a great variety of excitations and reactions, analyses of which are invaluable for understanding different kinds of motions of the nucleons within a nucleus. Heavy-ion collisions have also been indispensable for producing many exotic nuclear species, including four new chemical elements (numbers 106 through 109) during the past decade.

It is noteworthy that almost all nuclear-physics research to date has been possible only within the very limited domain of nuclei under conditions of low nuclear temperature and normal nuclear density. The vastly greater domain of high-temperature, high-density nuclear physics has just recently begun to be explored, using heavy-ion projectiles at relativistic energies. This too is currently a major frontier of the field.

Inevitably, fundamental new problems arise to challenge our understanding of nuclear physics. For example, although we now know how to explain certain nuclear phenomena in terms of the presence, within nuclei, of mesons in addition to protons and neutrons, we are not yet able to solve the corresponding equations of quantum chromodynamics (the quantum field theory that is believed to govern the manner in which these particles interact) to describe the effects in question.

Current efforts to solve this problem are particularly important because they hold the promise of new insights into one of the fundamental forces of nature, the so-called strong force. Indeed, the nucleus in general represents a uniquely endowed laboratory for investigating the relationships among the fundamental forces as well as the symmetry principles underlying all physical phenomena. Its key role in shaping our view of the cosmos is evident in the field of nuclear astrophysics, which provides information vital to our understanding of the origin and evolution of stars and of the universe itself. On the Earth, meanwhile, nuclear medicine (including the development and use of specifically tailored radioisotopes and accelerator beams for both diagnostic and therapeutic procedures), nuclear power (both fission and fusion), materials modification and analysis (for example, ion implantation and the fabrication of semiconductor microcircuits), radioactive tracers (used in a number of research areas ranging from geophysics to medical physics), as well as many routine industrial applications (including, for example, well-logging in test bores using miniaturized nuclear accelerators, food preservation by irradiation, and die hardening by ion implantation to reduce wear), and even the analysis of art objects are just a few examples of how the fruits of nuclear-physics research have found a multitude of useful and sometimes surprising applications in other basic sciences and in modern technologies, many of which have direct and significant impacts on society at large.

Much of this research is done with particle accelerators of various kinds. Some studies require large teams of investigators and high-energy accelerators, typically operated by national laboratories, while other, lower-energy studies continue to be performed at colleges and universities—typically by a professor and a few graduate students—using smaller accelerators or laboratory-scale equipment. Both produce fundamental advances in nuclear physics.

This very wide range of facilities and manpower requirements is among the unusual characteristics of nuclear physics. Maintaining the proper balance between the research programs of large and small groups is essential for overall progress in the field. Equally important is the balance between experimental and theoretical research, as well as the availability of state-of-the-art instrumentation and computers for the respective programs.

The major advances of the past decade of nuclear-physics research and the exciting prospects for its future—as well as some of the myriad ways in which nuclear physics has an impact on the other sciences and on society at large—constitute the subject of this nuclear-physics survey.

RECOMMENDATIONS FOR THE FUTURE OF NUCLEAR PHYSICS

In formulating the recommendations for the future of nuclear physics, as presented below, the Panel on Nuclear Physics has profited from extensive interactions between its members and the participants in the 1983 Long Range Planning Workshop of the Nuclear Science Advisory Committee (NSAC) of the U.S. Department of Energy and the National Science Foundation.