EXPLORING THE MATTER USING NUCLEAR PHYSICS

Shobhit, Govt. P.G. College Hissar

Abstract: This paper provides a long-term assessment of and outlook for nuclear physics. The first phase of the paper articulates the scientific rationale and objectives of the field, while the second phase provides a global context for the field and its long-term priorities and proposes a framework for progress through 2020 and beyond.

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INTRODUCTION:

Nuclear physics today is a diverse field, encompassing research that spans dimensions from a tiny fraction of the volume of the individual particles (neutrons and protons) in the atomic nucleus to the enormous scales of astrophysical objects in the cosmos. Its research objectives include the desire not only to better understand the nature of matter interacting at the nuclear level, but also to describe the nature of neutrinos and the state of the universe that existed at the big bang and that can now be studied in the most advanced colliding-beam accelerators, where strong forces are the dominant interactions.

The impact of nuclear physics extends well beyond furthering our scientific knowledge of the nucleus and nuclear properties. Nuclear science and its techniques, instruments, and tools are widely used to address major societal problems in medicine, border protection, national security, nuclear forensics, energy technology, and climate research. Further, the tools developed by nuclear physicists often have important applications to other basic sciences—medicine, computational science, and materials research, among others—while its discoveries impact astrophysics, particle physics, and cosmology, and help to describe the physics of complex systems that arise in many fields.

In the second phase of the study, developing a framework for progress though 2020 and beyond, the committee carefully considered the balance between universities and government facilities in terms of research and workforce development and the role of international collaboration in leveraging future investments.

This paper describes that nuclear science is a vital enterprise that provides a steady stream of discoveries about the fundamental nature of subatomic matter that is enabling a new understanding of our world. The scientific results and technical developments of nuclear physics are also being used to enhance innovation and economic growth and are having a tremendous interdisciplinary impact on other fields, such as astrophysics, biomedical physics, condensed matter physics, and fundamental particle physics. The application of this new knowledge is contributing in a fundamental way to the health and welfare of the nation.

Exploitation of Current Opportunities

Carrying through with the investments recommended in the 2007 Long Range Plan is the consequence of careful planning and sometimes difficult choices. A number of small and a few sizable resources have been developed since 2007 that are providing new opportunities to develop nuclear physics.

The Facility for Rare Isotope Beams

The Facility for Rare Isotope Beams is a major new strategic investment in nuclear science. It will have unique capabilities and will offer opportunities to answer fundamental questions about the inner workings of the atomic nucleus, the formation of the elements in our universe, and the evolution of the cosmos.

In recent decades, the nuclear science has enabled important experimental discoveries such as the nature of neutrinos and the fundamental reactions fueling stars, often with the aid of carefully designed experiments conducted underground, where the backgrounds from cosmic radiation are especially low.

FOUNDATION FOR THE FUTURE

The subject of nuclear physics has evolved significantly since its beginnings in the early twentieth century. To continue to be healthy the enterprise will require that attention be paid to elements essential to the vitality of the field.

Nuclear Physics at Universities

World-renowned universities are the discovery engines of the scientific enterprise and are where the bright young minds of the next generation are recruited and trained. As with other sciences, it is imperative that the critical value-added role of universities and university research facilities in nuclear physics be sustained. Unfortunately, there has been a dramatic decrease in the number of university facilities dedicated to nuclear science research in the past decade, including fewer small accelerator facilities at universities as well as a reduction in technical infrastructure support for university-based research more generally.

The dual role of universities—education and research—is important in all aspects of nuclear physics, including the operation of small, medium, and large facilities, as well as in the design and execution of large experiments at the national research laboratories. The vitality and sustainability of the nuclear physics program depend in an essential way on the intellectual environment and the workforce provided symbiotically by universities and the national laboratories. The fraction of the nuclear science budget reserved for facilities operations cannot continue to grow at the expense of the resources available to support research without serious damage to the overall nuclear science program.

In order to ensure the long-term health of the field, it is critical to establish and maintain a balance between funding of operations at major facilities and the needs of university-based programs.

The Department of Energy and the National Science Foundation should create and fund two national competitions: one a fellowship program for graduate students that would help recruit the best among the next generation into nuclear science and the other a fellowship program for postdoctoral researchers to provide the best young nuclear scientists with support, independence, and visibility.

Nuclear Physics and Exascale Computing

Enormous advances in computing power are taking place, and computers at the exascale are expected in the near future. This new capability is a game-changing event that will clearly impact many areas of science and engineering and will enable breakthroughs in key areas of nuclear physics. These include providing new understandings of, and predictive capabilities for, nuclear forces, nuclear structure and reaction dynamics, hadronic structure, phase transitions, matter under extreme conditions, stellar evolution and explosions, and accelerator science. It is essential for the future health of nuclear physics that there should be a clear strategy for advancing computing capabilities in nuclear physics.

Striving to Be Competitive and Innovative

Progress in science has always benefited from cooperation and from competition. Providing a culture of innovation along with an understanding and acceptance of the appropriate associated risk must be the goal of the scientific research enterprise.

Prospects for an Electron-Ion Collider

Accelerators remain one of the key tools of nuclear physics, other fields of basic and applied research, and societal applications such as medicine. Modifying existing accelerators to incorporate new capabilities can be an effective way to advance the frontiers of the science. Of course it is the importance of the physics and of the potential discoveries enabled by the new capability that must justify the new investment.

Nuclear physics is a discovery-driven enterprise motivated by the desire to understand the fundamental mechanisms that account for the behavior of matter. Nevertheless, for its first hundred years, the new knowledge of the nuclear world has also directly benefited society through many innovative applications.

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