

Executive Summary

One of the pillars of America's economic success is the strength of its research and development enterprise. The American Competitiveness Initiative (ACI) will build on this success and enhance innovation. Neutron measurement methods are indispensable for developing many of the key technologies and materials that will lay the foundation of future economic growth. Indeed, the unprecedented growth in the application of nano-scale functionality requires measurement methods, such as neutron scattering, that access the nano-scale. The NIST Center for Neutron Research (NCNR), which has a proven track record of providing world-class neutron capabilities to the R&D community, is especially well positioned to implement a range of instrumentation innovations. However, unfulfilled demand for instrumentation and limited resolution and neutron intensities present serious barriers to achieving the full potential of emerging scientific and technical opportunities.

The novel capabilities enabled by the proposed NCNR expansion and the addition of new instruments housed in a new facility illuminated by a bright new source of cold neutrons would help to overcome these barriers. The expansion would modernize a beam line that currently serves a single instrument into a multiplex system, optimized to serve five or more instruments simultaneously. State-of-the-art optical devices and neutron polarizing systems would significantly enhance instrument performance, and improved detectors would extend instrument sensitivity to weak signals. Such new capabilities are ideally suited to answer pressing questions that emerge as researchers try to understand and harness the fascinating properties of matter at the nano-scale and will provide opportunities for the U.S. to stay at the leading edge of science and technology development.

Cold Neutron Imaging

Cold neutron imaging offers unique measurement capabilities in support of American industry. Water and its spatial distribution play central roles in biological systems such as membranes, microfluidic devices, and many other physical systems of great practical importance such as hydrogen fuel cells. Cold neutron imaging coupled with new detectors will increase the current sensitivity to water and its spatial distribution by orders of magnitude. This will open new opportunities to study water transport mechanisms in geological samples, biological systems, and hydrogen fuel cells. The deep penetration and enhanced phase sensitivity of cold neutron imaging would enable high throughput, non-destructive evaluation (crack and defect detection, residual stress) of mechanical components to improve manufacturing techniques.

Soft Materials

Practical applications of soft materials like surfactants, colloids, polymers, and biological macromolecules are widespread in our modern economy. Neutron scattering is an essential tool for characterizing the structure and dynamics of these systems because neutrons are extremely sensitive to hydrogen, which permits detailed investigations of hydrogenous materials. Neutrons also see hydrogen and deuterium quite differently which allows scientists to enhance structural features by chemically substituting

deuterium for hydrogen. Because neutrons are neutral particles, they can penetrate deeply into materials. This property can be exploited to study complex systems under confinement or extreme environments, or even to observe materials during manufacturing. And neutrons can probe key molecular motions over a wide range of time and length-scales that are not accessible by any other technique.

While soft materials are already ubiquitous in our lives, improvements in our ability to understand and control their function will lead to even broader applications in the future. These new applications could include: smart biomedical materials; polymer electrolytes and membranes for advanced batteries and hydrogen fuel cells; polymer thin films for advanced coatings and microelectronics; and materials for drug encapsulation and delivery; and advanced nanocomposite materials. Advanced neutron scattering methods are essential to realizing this promise.

Hard Materials and Chemical Physics

Controlling the behavior of materials and small molecular systems at the nanometer scale is central to a wide range of technologies with immense societal impact. The ever-growing demands for greater data storage and faster data retrieval and processing require improved characterization of complex magnetic structures. Because neutrons couple strongly to magnetism, they are ideal for this task. Neutrons are also sensitive to absorbed hydrogen and can characterize its diffusive motion, which makes them essential to the goal to develop new materials to store and transport hydrogen efficiently. Neutrons are also crucial to better understand and control chemical processes and catalysis. Finally, the development of new materials that will fuel the growth of future technologies such as quantum computing, solid state refrigeration, and next generation sensor technologies require improved understanding that can only be obtained using neutron methods.

To advance the performance of these important functional materials, methods that employ and measure the magnetic polarization of the neutron are required. With polarized beams also come new options to enhance resolution without intensity loss through spin resonance techniques. The proposed expansion of the NCNR provides the opportunity to develop instrumentation that takes full advantage of modern polarization techniques to create measurement capabilities that don't currently exist.

Measurements of Neutron Properties

Precision measurements of fundamental neutron properties expand our knowledge of the basic forces of nature and reveal new physics to help explain the birth and development of the universe. These include studies of neutron beta decay, weak nuclear interactions, and the neutron electric dipole moment. Some experiments benefit from large, divergent beams with the highest possible flux. Others require smaller beams with high brightness. The NCNR expansion offers beamlines with substantially higher neutron flux and brightness tailored to optimize the performance of these experiments, with state of the art neutron optics and new opportunities for high beam polarization and precision polarimetry. It enables an exciting new generation of experimentation that will address the most pressing problems in this field and advance the frontier of fundamental physics.