Title

Advanced Moderators for intense cold and ultracold neutron beams in materials research Enhanced Cold Neutron Beam Production for Materials Research and Applications via Advanced Moderators

Background Situation Analysis

For over 50 years research reactors and spallation neutron sources have been used for fundamental and applied research in the areas of material science, earth science and nuclear physics. The results of these studies cannot only be found in scientific journals, but also in our daily lives.

* Today many of us relay on tools like cell-phones, ipods or ipads. None of these gadgets would be useful without rechargeable batteries. The scientific base for this was laid decades ago, by studying magnetism in materials using neutrons.
* The Kubas interaction, which is at the core of every design of hydrogen storage materials, would have properly never been discovered without neutron scattering.
* Neutron radiography is the only none destructive technique that can be used in Archeology to look inside objects. Neutron radiography is also used to study fuel cells.
* Small angle neutron scattering is heavily used by the detergent industry to study the formation of micelles in surfactants in solution, which helps them to improve their products.
* Ultracold neutrons can be used as an alternative to small angle scattering investigations and fundamental physics research.

These are only a few examples where neutron scattering has made in impact on lives of people that are not working in research, and it shows that there will be a great demand for neutron scattering in the coming decades.

Since a while, research reactors have supported developments in neutron beam research, new materials, and component integrity testing, and these facilities are expected to continue to do so in the coming decades. However, today’s technical, economic, and social realities place demands on neutron research that many research reactors are unable to satisfy currently. In this proposal, we outline a project that can effectively utilize small research reactors in an effort to increase the cold neutron flux available at neutron sources of all types (ranging from small accelerator driven sources to research reactors of all sizes, and even spallation sources). The project will also initiate collaborative research activities among several small research reactors and the major international sources thereby opening up new opportunities for both independent and collaborative research at small research reactors in the future.

Neutron scattering encompasses all scientific techniques whereby the deflection of neutron radiation is used as a scientific probe. Neutrons readily interact with atomic nuclei and magnetic fields from unpaired electrons, making a useful probe of both structure and magnetic order. For many good reasons, moderated neutrons provide an ideal tool for the study of almost all forms of condensed matter. Firstly, they are readily produced at a nuclear research reactor or a spallation source. Normally in such processes neutrons are however produced with much higher energies than are needed. Therefore moderators are generally used which slow the neutrons down and therefore produce wavelengths that are comparable to the atomic spacing in solids and liquids, and kinetic energies that are comparable to those of dynamic processes in materials.

However, moderated neutron beams are produced by a slowing-down and thermalization process, which suffers from very low efficiency. Indeed, only few neutrons which enter the moderator will appear in the useful neutron beam direction. The most inefficient step in this process occurs when neutrons are emitted from the face of the neutron moderator following a cosine distribution, and only the small fraction, that happen to be going along the neutron beamline, make it to the sample position. Following a 1/r2 approach, it is simple to show that, for unguided beams, only one in ten million neutrons makes it to a sample position at 10 m from the moderator face. When the probability of interacting with the sample, probability of being analyzed properly (polarizers, crystals, etc.), and the probability of detection are factored in, it is easy to conclude that only 10-10 neutrons, or less, emitted from the moderator face actually contribute to a successful experiment. Reentrant moderators can improve upon this by factors on the order of 2 or 3, as demonstrated in several reactor sources and the grooved moderators deployed at spallation sources. Recently, an extension of this idea, the convoluted moderator in which layers of conventional moderating material is interleaved with single crystals of silicon, has also been demonstrated. Even bigger gains are available through the use of instrumentation employing neutron guides (which act like light-pipes channeling neutrons down the instrument). Unfortunately, the gains realizable from guides are limited due to the relatively small angular acceptance of the guides, and the susceptibility of the guide design to radiation damage (which limits how close to the moderator the guide may be positioned).

At several facilities research is underway to develop moderators which focus neutrons beams in a preferred direction as opposed to emitting neutrons isotropically. In addition to the above-mentioned convoluted moderator idea, another idea being considered is the use of high-albedo materials that utilize multiple scattering at the mesoscopic scale to mimic the action of neutron guides with large angular acceptance for long wavelength neutrons and are expected to be highly resistant to radiation damage. For example, recent use of diamond nanoparticles for cold, very cold and ultracold neutrons revealed very promising results at ILL (France). A significant increase of the neutron brightness was observed for wavelengths above 7Å reaching a factor of 5 at 20 Å using this material. Other similar studies are on-going at SNS (USA), JPARC (Japan), ISIS (UK), and elsewhere. It may be possible to use these materials on the moderator itself, or outside of the moderator, essentially extending the moderator along the direction of the extracted neutron beam.

Identifying and testing these high-albedo materials for neutron scattering is a critical step in the process. Small scale accelerator facilities at Sapporo (Japan), Bariloche (Argentina) and LENS (USA) are collaboratively developing new moderator experiments and simulations to improve available cold neutron fluxes. These facilities will be critical to the development of advanced moderators, including those with materials exhibiting mesoscale scattering.

Making progress in this field will require coordinated research among several institutions, with activities ranging from the development of new simulation tools, to the experimental characterization of the scattering from nano-structured materials (as candidate high-albedo elements) over a range of angles and neutron wavelengths, and the experimental investigation of candidate designs and materials in test moderators. We anticipate a CRP that includes experts on simulating neutron facilities with modern neutron transport codes from some of the world’s premier neutron sources, researchers at research reactors in developing countries who need experience with such codes, and researchers at facilities capable of testing new moderator designs experimentally. A key element in the program is identifying and characterizing the scattering properties of candidate materials, and assessing the influence of processing parameters on those properties. This materials survey task is one that is well suited to smaller research reactor facilities in developing countries.

Nuclear Component

Neutrons are produced by various means, from isotropic sources, generators, accelerators, research reactors and spallation sources. Scientists and other users of neutron beam are requesting more intense flux of neutron in specific wavelength, where their application will lead to improved knowledge and understanding of investigated materials. High energy neutrons, produced at research reactors or spallation sources, need to be moderated to reach the desired energy. Cold neutron production requires better understanding of neutron cross sections for old and new moderator materials. Simulations and combination of various modelling of reactions are mandatory to enhance the new moderators. Experiment at small scale facilities (small spallation source, or low flux research reactor) will bring the full understanding of moderator material behaviour in some controlled environment.

CRP Overall Objective

Enhancement of cold neutron beam flux for applications in materials research. In the field of ultracold neutrons gain factors in the order of 1000 can be expected which opens new fields of research.

Specific Research Objectives

1. Identify high albedo materials exploiting mesocale scattering
2. Execute experiments demonstrating gains in cold neutron brightness using the identified materials
3. Implement anisotropic scattering of mesocale physics within neutron transport codes

Expected Research Outputs

1. Document five materials with high albedo to be considered for experiments
2. Complete and document at least three experiments campaigns using high albedo materials
3. Improve scattering kernel and treatment in small angle scattering neutron transport codes
4. Simulate experiments and compare to observations

CRP Expected Research Outcomes

1. Identified new moderator materials which will enhance the production of cold neutron at research reactor and spallation sources
2. Developed the ability to model mesoscale physics in existing neutron transport codes.
3. Prepare the floor for new ultracold neutron factories at advanced neutron sources and as upgrades of existing ones.

List of potential participating countries

Argentina, Australia, Austria, Belarus, Brazil, Canada, China, Czech Republic, Denmark, European Union, France, Germany, Hong Kong - China, Hungary, Indonesia, Italy, Japan, Korea - Republic of, Malaysia, Netherlands, Poland, Romania, Russian Federation, South Africa, Spain, Sweden, Switzerland, United Kingdom, United States of America, Vietnam.