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ScienceDirect
C. R. Physique 8 (2007) 715–716
Comptes Rendus Physique
http://france.elsevier.com/direct/COMREN/

Neutron scattering/Diffusion de neutrons

Foreword

The maturity of neutron scattering methods for scientific research was recognized in 1994 when Clifford Shull and Bertram Brockhouse shared the Nobel prize, the former cited for showing 'where atoms are', and the latter for 'what atoms do'. These statements crystallize the use of neutron scattering in condensed matter research in minimal form, but there is no doubt that behind the scenes one can find a much more intricate framework of possibilities for studying structure and dynamics.

The exceptional power of neutrons stems from the facts that (i) their interaction with atomic nuclei and microscopic scale magnetisation can be treated quantitatively; (ii) the energies of conveniently thermalised neutrons can be chosen to match with the range of energies characteristic of dynamic processes in condensed matter; and (iii) the wavelengths of these neutrons correspond to the length scales typical of interatomic distances. Combining these aspects, one has a handle for the investigation of correlations in space (from atomic, below nm scale up to large objects of μm size) and time (from 10^{-14} s up to 10^{-7} s) in a quantitative framework that is unique to neutron scattering.

Over the years neutron diffraction and inelastic neutron scattering have become essential tools for revealing the detailed behaviour of condensed matter. Through the observation of elastic scattering, arrangements of atomic nuclei and magnetic moments that remain unchanged in time were used to describe long-range, crystalline order and ordering processes. In parallel, energy resolved (inelastic) neutron scattering methods provided the possibility of understanding critical phenomena (universality classes of phase transitions, soft modes, Goldstone modes), elementary excitations (phonons and magnons) and relaxation processes, not only in ordered matter, but also in liquids and in complex matter such as polymers. The results obtained using neutrons confirmed several theoretical concepts that have become the very foundations of condensed matter physics.

The collection of articles presented in this 'dossier' intends to give a flavour of the extent of modern neutron scattering methodology. The themes chosen cannot pretend to cover completely the spectrum of research that is actually done with neutron scattering methods, the aim is more to highlight the diversity and depth of the opportunities that are open for scientists using these techniques.

Since the pioneering era of Shull and Brockhouse, the available neutron sources, based on nuclear fission in a controlled chain reaction, have not much improved quantitatively. The use of the technique has progressed essentially due to creation of dedicated reactor sources optimized for the production of neutron beams with desired properties in terms of wavelength (energy) distribution, and the neutron optics devices that are essential for improving instruments in terms of count-rate, resolution, and flexible operation. This progress with neutron instrumentation has led to orders of magnitude gains in data acquisition times and resolution power, and with the associated improvements of data analysis methods it has been possible to maintain the technique at the forefront of research. The present special issue does not cover the instrumental aspects in detail, but authors describe some of the basic principles in relation to the research performed.

Meanwhile, the expansion in the use of the technique became possible through the organization of the neutron centres. The teams affiliated to neutron facilities, in charge of maintaining and improving the instruments and of conducting their own scientific programs, are engaged as well in receiving research proposals from any interested laboratory from academia and industry. This sharing of expertise opens collaborations for extending small-scale lab-

doi:10.1016/j.crhy.2007.10.016

oratory research using the power of neutron scattering when the need arises.[1] This mode of operation is productive in terms of science, and cost-effective in terms of funding.

Already at the end of the 20th century it was recognized that the present neutron sources are at the 'end of the line', as explained in the contribution of F. Mezei; the thermodynamic limits have been reached and an increase of source brightness is no longer achievable. Creation of neutrons by the spallation process using proton accelerators aiming at a heavy element target is more advantageous with respect to production of neutrons compared to the production of heat, and it is now admitted that the high efficiency sources of the future will be spallation sources. Two of these are entering the scene, one already operational in the United States, the other to come in Japan. In Europe, conclusive experience on spallation neutron sources has been obtained at the ISIS pulsed facility in the United Kingdom and at the Swiss Neutron Source at Paul Scherrer Institute. The European Spallation neutron source project has been discussed since the early 1990s, and is now considered to be the choice of the future, that needs to be realized without further delay.[1]

The contributions of this special issue give many reasons for justifying the pursuit and development of neutron techniques. The breadth and depth of the investigations presented include detailed work on fundamental problems of modern solid state physics (high-T_c superconductivity, Sidis and colleagues, quantum magnetism, Grenier & Ziman), highlighting the power of present day spectrometers for the investigation of single crystal samples. A vast range of possibilities is revealed by the studies on strains in engineering objects (Withers), passing by in-situ methods applicable to processing (chemical reactions), operational devices (batteries) and non-destructive examination of archaeological objects (Isnard), extending to the structure and dynamics of soft matter (Boué, Richter & Monkenbusch) and themes of biophysical interest (Fragneto & Rheinstädter). The challenges of the nanoscale are met in the studies using reflectivity methods (Ott) and in the studies of the dynamics of molecular motion in confinement (Rols and colleagues). Study of liquid state properties is a traditional application of neutron scattering, still in progress (Leclercq-Hugeux and colleagues). The use of external control parameters, such as a magnetic field (Grenier & Ziman) or pressure (Mirebeau) is an interesting additional dimension, where continuous efforts are being made.

As a method relying on large-scale infrastructures, neutron scattering is at present confronted with strong competition coming from other techniques, such as synchrotron radiation, and is also feeling the shift of interest from the very basic concepts to the study of functional materials and application oriented research. In many respects neutron methods remain a reference, especially for the study of magnetism, or in the case of soft matter, a tool of choice, still highly productive at existing sources.[1] It is worthwhile to note that neutron users in academia and industry, and professionals at the facilities are fully engaged in the effort of facing the challenges listed above, as shown in this issue by studies focussing on nanoscale structures and surfaces, life sciences as well as on in-situ processes and engineering.

We are convinced that there is still place for progress and need for consolidation in the future of neutron scattering. The dream is to have sources, instruments and data processing methods that will permit the production of movies of processes in condensed matter. The objects of study might include a support for information processing, an operating catalyst for clean and sustainable energy production, the failure mode of a spacecraft component, or with more ambition, even a living cell.

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Available online 26 November 2007

[1] Further information on the existing neutron sources, new projects and user organizations can be found following the links located at the European Neutron Portal http://neutron.neutron-eu.net/.