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VIEWPOINT

Neutron polarimetry: an experimental tool for distinguishing between conflicting magnetic structure models

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Abstract
Neutron polarimetry is a novel technique which allows unique information to be obtained. Its merits and challenges are briefly reviewed.

The possibility of the investigation of magnetic properties of materials on the atomic level makes neutron scattering the technique of choice for the experimental characterization of magnetic order. Ever since the first neutron scattering experiments and the confirmation of the existence of antiferromagnetic order, neutron scattering experiments have provided valuable information. This has resulted in an increased understanding of magnetic structures and revealed the huge variety of possible magnetically ordered states.

For conventional measurements, unpolarized neutrons are used to determine the magnetic contribution to the scattering for both powder samples and single-crystal investigations. While nuclear scattering also contributes, for many cases of interest the magnetic intensity can be readily identified if it occurs at different points in reciprocal space. However, if the magnetic unit cell does not increase compared to the nuclear one, magnetic and nuclear scattering occurs superimposed on the same Bragg peak positions. For these structures, and for more complicated magnetic arrangements, polarized neutrons are employed to unambiguously separate magnetic and non-magnetic scattering. For such experiments the fact is used that the magnetic interaction contains a term

$$\vec{q} \times \left(\vec{M} \times \vec{q} \right)$$

where $\vec{q}$ is the scattering vector and $\vec{M}$ the magnetization. This results in magnetic scattering occurring only for magnetization components which are oriented perpendicular to the scattering vector. Using the polarization of the incident neutron beam as an experimentally controllable variable, the neutron spin is flipped by the magnetization components perpendicular to the neutron spin direction (which is defined by a small external magnetic field of order 10^{-3} T) while the magnetization component parallel to the magnetic field direction scatters neutrons without a spin flip. Using these dependences, the magnetic scattering contribution can be isolated from other scattering contributions.

There are, however, some cases for which possible magnetic models give very similar magnetic scattering intensity despite a significant difference in the arrangement and orientation of magnetic moments on an atomic scale. For these samples it is not sufficient to only determine the magnetic scattering intensity, as insufficient variation in intensity does not allow an unambiguous selection of the correct magnetization model to be made in the light of the experimental accuracy.

It is for these cases that neutron polarimetry offers unique possibilities. One recent example is the paper by Brown and Chatterji [1]. Essentially, this technique allows one to determine the polarization vector of the scattered neutron beam. Compared to the intensity, which is one number only or, for the case of polarized neutrons two numbers with intensity for the neutron spin flip and non-spin flip scattering, a polarimetric measurement yields the three components of the vector. The information content of three numbers is significantly increased. In addition, if the polarization direction of the incident neutron beam is also varied with respect to the crystallographic axis the full polarization matrix can be obtained. The polarization of scattered neutrons can be related back to the magnetization on the atomic scale. It turns out that this increase in information is able to allow a much clearer and informed distinction to be made between the scattering for different magnetization models.

While in principle neutron polarimetry is able to offer an increased information content of the experimental data, the gain comes at a price. Experimentally the set-up is much more cumbersome, and the measurement process more tedious. Accurate alignment is crucial. Furthermore, the need to determine the neutron polarization vector requires special experimental conditions, such as the sample being positioned in a magnetic field-free space. The transition between a guide field outside the sample space to a field-free sample region is achieved using superconducting shields. Separating the incident polarization field from the polarization field for the scattered neutron beam is a challenge which, however, has been mastered. While the requirement of a field-free region can be relaxed to allow measurements at very low magnetic fields [2], at least for neutrons of longer wavelength, the experimental constraints and requirements are still demanding. It is to the credit of the pioneers of this technique, Francis Tasset and Jane Brown at the ILL in Grenoble, and others, that this experimental technique has been mastered in a routine manner.

The advantages of neutron polarimetry have been exploited for the determination of magnetic structures and for distinguishing magnetization models which give rise to very similar magnetic scattering intensities. A recent paper by Brown and Chatterji [1] addresses the magnetization in rare-earth-based manganites $HoMnO_3$ and $YMnO_3$, which are currently being investigated intensely due to their potential and relevance for application. Neutron polarimetry has allowed Brown and Chatterji to uniquely identify the correct magnetization model, thereby allowing a more informed interpretation of other experiments on these samples.

Neutron polarimetry has by now a proven record of success, and the list of samples being investigated with this technique continues to grow: Cr_2O_3 [3], Mn_3Sn [4], CuO [5], $CeCu_2$ [6], $U_{14}Au_{51}$ [7], to name but a few. The experimental possibility to extract the full information of a scattered and spin-polarized neutron beam obtainable by a scattering experiment is proving a very valuable tool for the investigation of more complicated and challenging magnetic structures. It is, in a way, the ultimate that can be achieved with a spin-polarized neutron scattering experiment. The neutron scattering community is grateful for the dedication and commitment shown by the pioneers of this technique, and the early experimenters, without whom this technique would not have achieved its present position as a standard experimental technique available to all by application to the ILL.

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