USING HOT NEUTRONS TO SPOT SMALL SOURCES OF MAGNETIC ANISOTROPY

M. Rotter[1], M. Doerr[1], A. Lindbaum[2], M. Loewenhaupt[1], B. Beuneu[3]

[1]Institute für Angewandte Physik (IAPD), Technische Universität Dresden, D-01062 Dresden, Germany
[2]Institut für Festkörperphysik (IFP), Technische Universität Wien, A-1040 Wien, Austria
[3]Laboratoire Léon Brillouin, CEA-CNRS, Saclay, 91191 Gif sur Yvette Cedex, France

What does happen, if the major source of magnetic anisotropy - the crystal field - is switched off ? Is there any other important source of anisotropy or will the system be magnetically isotropic despite its crystalline structure? These questions can be addressed by investigating Gadolinium (Gd) compounds by magnetic diffraction experiments.
Gd has a very large spin moment, but no orbital moment in its ground state (L=0), and therefore it is not sensitive to the crystal field. The isotropic interactions (such as RKKY exchange interactions etc.) dominate the magnetic properties and lead to ordering temperatures of more than 100 K for a large number of Gd compounds. The small but finite magnetic anisotropy of the L=0 rare earth compounds is topic of various speculations about it's origin: crystal field and exchange effects coming from higher multiplets, or dipole interaction? These sources of anisotropy can be tested by comparing models with experiments.
One of the key factors in such an investigation is the accurate determination of the moment direction in these compounds. Whereas the magnetic propagation is determined by the large isotropic interactions, the moment direction is determined by the small anisotropic interactions. A general treatment of anisotropic interactions has been given in [1] and this model can be directly used for the calculation of the dipolar anisotropy. If the propagation vector t of a magnetic compound has been determined from the diffraction data, it is possible to calculate that orientation of the magnetic moments in the ordered state that is favoured by the dipole interaction, and compare it to the experimental one.
However, in practice such an idea suffers a major drawback, because Gd has a very large absorption cross section for neutrons. But the absorption coefficient of Gd depends strongly on the neutron energy. At wavelengths below 0.06 nm, the absorption is small enough to enable an accurate determination of the moment direction by magnetic neutron diffraction experiments, due to the large moment of Gd. Most favourable systems, which can be investigated, are antiferromagnetic compounds.
Because it is installed on a hot-source, the 7C2 diffractometer for liquids of the LLB (neutron wavelength of 0.058 nm) is a powerful tool for such investigations, in spite of its low resolution. We have performed experiments on powdered samples of $GdAu_2Si_2$, $GdAu_2$, $GdAg_2$ and $GdCu_2In$. The absorption to signal ratio was reduced using a hollow cylinder geometry for the sample.

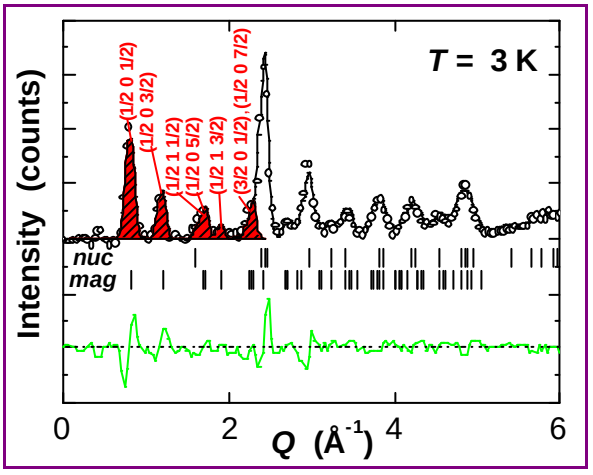

Figure 1. Neutron diffraction patterns of $GdAu_2Si_2$ at T= 3 K. Black line: calculated spectrum, green line: difference between calculated and measured intensity. The positions of nuclear peaks and the magnetic satellites with strong intensity are indicated by the vertical bars.

To give an example we discuss $GdAu_2Si_2$ in more detail. $GdAu_2Si_2$ orders (fig. 2) antiferromagnetically at the Néel Temperature T_N = 12 K [2]. Diffraction patterns were taken at 25 K and 3 K (fig. 1). The pattern at 25 K in the magnetically disordered state can be indexed according to the tetragonal $ThCr_2Si_2$ structure. At 3 K the best fit is obtained for a propagation vector t = (1/2 0 1/2) and a Gd moment of 6.2 μ_B/Gd oriented parallel to [010], i.e. perpendicular to the propagation vector.
The influence of the classical dipole interaction was estimated by a calculation of the Fourier transform of the dipole interaction at the propagation vector t. The largest eigenvalue corresponds to the moment direction [010], in agreement with the diffraction experiment

Taking the results of the 7C2 measurements as a basis, the model has been applied to a large number of other Gd systems using available data from literature. In most cases the observed magnetic anisotropy can be attributed to the dipole interaction. So our experiments indicate that in Gd systems all other interactions are isotropic to a very high degree of accuracy and that the small dipolar interaction determines the anisotropy of these systems. This is true for ferromagnets as well as for antiferromagnets. It is remarkable, that although the magnetic anisotropy of Gd compounds is much smaller than that of other rare earth compounds, it can be predicted with high accuracy from first principles.

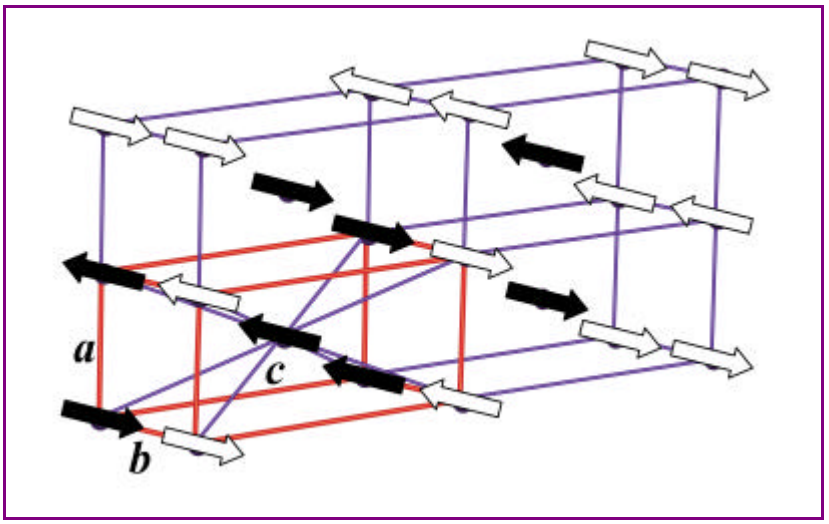

Figure 2. Magnetic unit cell of $GdAu_2Si_2$. Domain with the propagation t = (1/2 0 1/2) and magnetic moments parallel to [010] (due to the tetragonal symmetry there exist two domains). For clarity we show only the Gd sublattice.

References

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