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# LOCALISED MAGNETIC EXCITATION MODE IN HEMATITE NANOPARTICLES

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The magnetic dynamics of nanoparticles is a challenging field both technologically and scientifically. As the size of a particle decreases and enters the nanometer scale the magnetic properties change and new dynamical phenomena appear. An example is superparamagnetic relaxation, in which the direction of the total magnetic moment of the particle performs a spontaneous reversal due to thermal fluctuations. Superparamagnetism is seen in antiferromagnetic particles as well – here each sublattice reverses it magnetisation. Another example of magnetic nanoparticle dynamics is collective magnetic excitations. Here the magnetic (sublattice) moments move coherently around its ground state position, performing a precession. These excitations correspond to spin waves with $q = 0$.

Nanoparticles of the canted antiferromagnet hematite ($\alpha$-$Fe_2O_3$) are particularly interesting due to the complicated magnetic structure of the bulk material.[1] Using high-resolution neutron scattering we have earlier observed both superparamagnetic relaxation and collective magnetic excitations in nanoparticles of hematite.[2, 3] Super-paramagnetism was seen as a broadening of the elastic peak in a quasielastic scan at the antiferromagnetic (1 1 1) scattering vector, whereas the collective magnetic excitations appears as broad side peaks centred at ±0.26 meV. At temperatures above 150 K the superparamagnetic relaxation time was found to agree with the (Arrhenius type) Néel-Brown law, but small deviations - at the limit of the experimental resolution - were found at lower temperatures.[3]

Recently, we have discovered a new mode of magnetic dynamics in hematite nanoparticles.[4] The signal is visible as an inelastic peak around 1.0 – 1.3 meV at the antiferromagnetic (100) scattering vector, and the peak is localized in both $q$ and $\omega$, see Fig. 1. Our neutron scattering studies of this mode includes measurements in applied fields up to 9 T as well as polarisation analysis. We present a detailed model for the mode and its field dependence.

Our results show that two collective excitation modes exist in hematite nanoparticles, a low-frequency mode and a high frequency mode. In the previously observed low-frequency mode, the (elliptical) precession is mainly in the easy plane. The newly observed high-frequency mode is found to have mainly out-of-plane precession. The modes correspond to two $q = 0$ spin waves with (different) anisotropy gaps. Whereas the existence of two anisotropy gaps are known from bulk hematite[1], the localisation of the nanoparticle modes provides direct evidence for the predicted discrete spin wave spectrum in magnetic nanoparticles.[5]

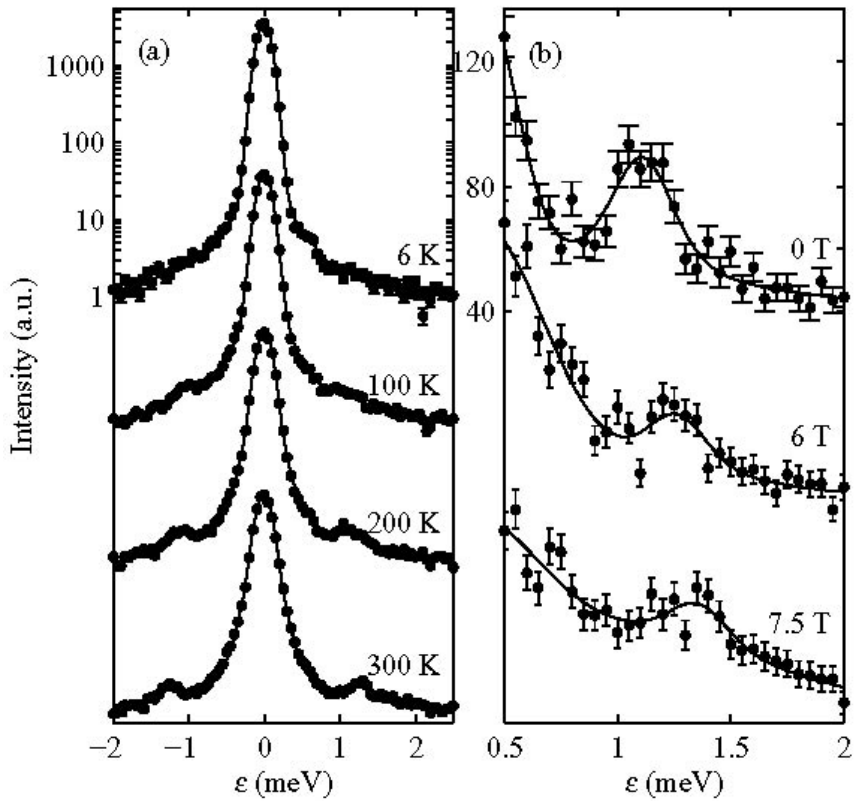


**Fig. 1.** Inelastic neutron data on 16 nm hematite nanoparticles taken at the (1 0 0) antiferromagnetic scattering vector. The left panel shows the temperature dependence of the elastic peak and the side peaks, shown on a logarithmic scale. These data were taken at the RITA-2 spectrometer at PSI. The right panel shows a zoom-in on one side peak as a function of applied field, shown on a linear scale. These data were taken at the TASP spectrometer at PSI.

We have varied the temperature in the range 6 - 300 K. The energy of the newly observed mode is found to increase with increasing temperature, reflecting the changes in the out-of-plane anisotropy. In hematite nanoparticles, this anisotropy differs from the bulk material resulting in a suppression of the Morin (spin-flip) transition for nanoparticles of diameters less than 20 nm. Our results give direct access to measuring the anisotropy, thereby shedding more light on the suppression of the Morin transition in nanoparticles.

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