Experimental report

18/02/2019

Proposal:	**5-53-266**	**Council:**	10/2016
Title:	Dipolar correlations in hexagonal and square arrays of magnetic nanoparticles		
Research area:	Materials		

This proposal is a new proposal

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Samples: $CoFe_2O_4$ (on silicon substrate)

Instrument	Requested days	Allocated days	From	To
D33	4	3	17/02/2017	20/02/2017

Abstract:

We propose to investigate the magnetic correlations of cobalt ferrite nanoparticles in two dimensional hexagonal and square arrays by polarized grazing incidence neutron scattering. The samples are prepared homogeneously by evaporation-induced self-assembly with close packed domains of long-range ordered particles across several micrometers and have been characterized by electron microscopy, macroscopic magnetization measurements, x-ray reflectometry and grazing incidence x-ray scattering. As a result of the experiment, we aim to observe for the first time emergent superferromagnetic and superantiferromagnetic states by polarized GISANS and to enhance thereby the understanding of the dipolar coupling between magnetic nanoparticles, which will be indispensable in any future planning of applications for two dimensional nanoparticle assemblies.

Dipolar correlations in hexagonal and square arrays of magnetic nanoparticles

Ordered assemblies of magnetic nanoparticles have attracted great interest in fundamental research, *e.g.* in the study of dipolar and exchange coupling, as well as for technological applications in spintronics and information technology [1, 2]. Single layers of ordered nanoparticles are especially interesting due to their relevance to potential 2D devices and as model systems for fundamental studies. For magnetic nanoparticles numerical simulations suggest that dipolar coupling leads to a super antiferromagnetic state in square arrays and a super ferromagnetic state in hexagonal arrays [3].

Within our study, we carried out polarized grazing incidence small angle neutron scattering (polGISANS) experiments to determine the magnetic correlations in long-range ordered samples of cobalt ferrite nanoparticles in hexagonal and square arrays. The incident angle was set to the critical angle of cobalt ferrite at 0.35° and the samples were measured at low temperatures of 5 K. Measurements were performed at guide field (5 mT), at a magnetic field of 4 T, in remanence (5 mT), and at a negative field of -100 mT. The magnetic field was applied in-plane of the substrate and in beam direction (Fig. 1), as well as perpendicular to the beam direction (Fig. 2). Additionally we performed measurements at 250 K with the field parallel & perpendicular to the beam direction.

The detector data was acquired in steps of 10 minutes, where the neutron polarization was flipped at every step. For each channel the data was integrated over a time of 2 – 4 hours and for analysis the data along the Yoneda line was projected in a small stripe along q_z.

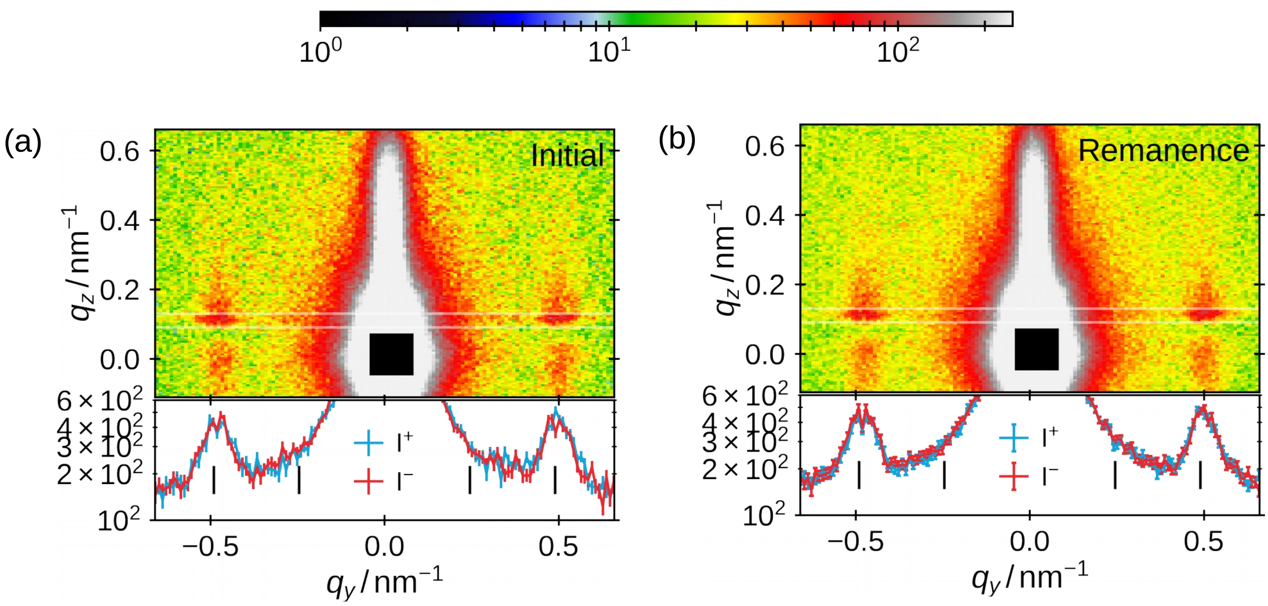

Fig. 1: Polarized GISANS at 5 K of nanocubes in a square array at (a) guide field after zero-field cooling and (b) in remanence after saturation at 4 T. The projected Yoneda line is marked by two white stripes and shown in the lower insets.

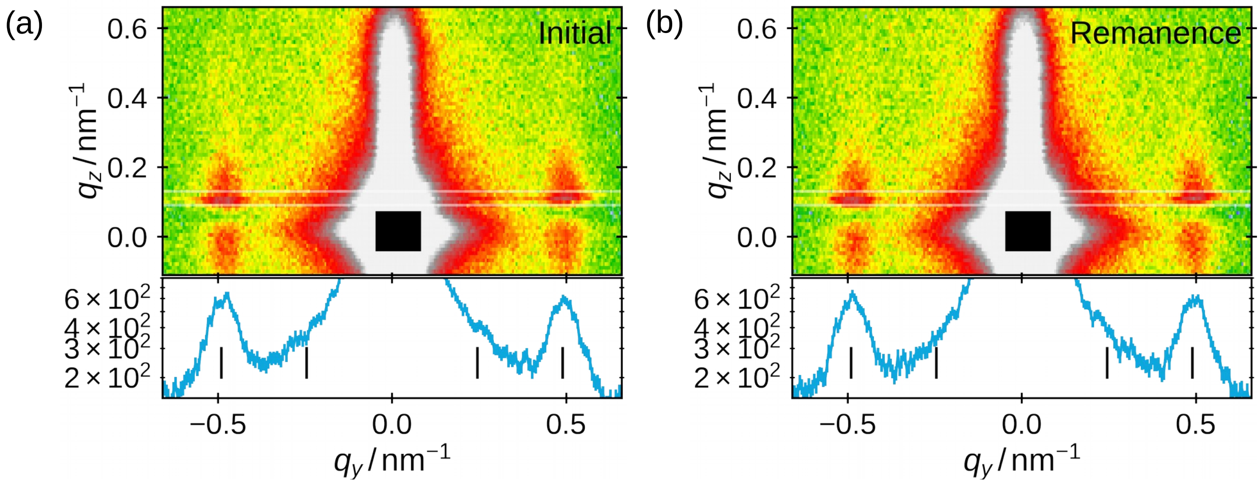

Fig. 2: GISANS at 5 K of the same sample of nanocubes in a square array as shown in Fig. 1, but with the saturating field of 4 T applied perpendicular to the beam direction and without discrimination of the polarization. Shown are the measurements at (a) guide field after zero-field cooling and (b) in remanence.

Comparing the scattering intensity in the Yoneda line for the measurements at guide field, saturation and remanence, we see in each case the first order Bragg peak originating from the regular nanoparticle spacing. In the case of the nanocube square lattice, we expected an emergent peak between the direct beam and first order peak due to a super antiferromagnetic ordering of the magnetic moments in the lattice. This super antiferromagnetic peak should be visible in both neutron channels. However, this is not observed in any case at the expected peak position as the difference is not distinguishable from noise.

Further analysis of the sample data in combination with the structural analysis by GISAXS and XRR, as well as the analysis of the macroscopic magnetization state is on going to resolve the observed magnetic ground state.

References:

[1] S. Bader, *Rev. Mod. Phys.* **78**, 1 (2006)

[2] S. A. Majetich *et al.*, *ACS Nano* **5**, 6081-6084 (2011).

[3] V. Russier, *J. Appl. Phys.* **89**, 1287 (2001).