

Using Polarization Analyzed SANS to investigate Magnetic Nanoparticles

Magnetic nanoparticles and nanoscale structures are intriguing in part because of the exotic properties that can emerge compared with bulk. A reduction of net magnetic moment per atom in magnetite (Fe_3O_4) with decreasing nanoparticle size, for example, is known to occur. This decrease in magnetism has been hypothesized to originate from surface disordering or anisotropy-induced radial canting [1-3], resulting in proposed morphologies that are difficult to verify using conventional magnetometry. Yet, other experiments [4-6] suggest that in certain circumstances oleic acid coating may preserve the surface magnetism. When the nanoparticles are brought close together, additional dipolar interactions come into play.

Application of Polarization Analyzed Small-Angle Neutron Scattering (PASANS) to 9 nm magnetite nanoparticles closed-packed into face-centered crystallites of up to a micron revealed that at nominal saturation the missing magnetic moments unexpectedly interacted to form ordered shells 1.0 to 1.5 nm thick with a magnetic component canted perpendicular to their ferromagnetic cores between 160 to 320 K [7]. These shells additionally displayed intra-particle “cross-talk”, i.e. they selected a common orientation over clusters of tens of nanoparticles (averaging to zero across the entire sample). However, the shells disappeared when the external field was removed and inter-particle magnetic interactions were negligible (at 300 K), confirming their magnetic origin.

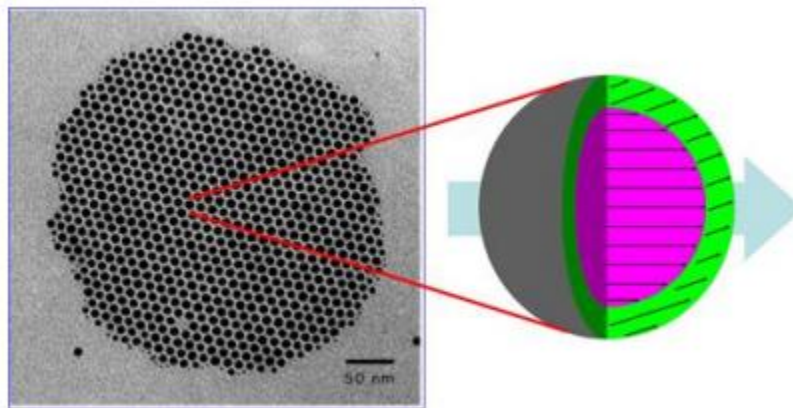


Figure 1 depicts a simplified schematic showing the uniformly canted magnetic shell (green area) with a component that is perpendicular to the applied field of 1.2 Tesla (shown as a light blue arrow).

The canted shell formation is thought to result from the fact that the nanoparticles' crystalline axes are randomly oriented and fixed in place with oleic acid with respect to the applied magnetic field. Each nanoparticle has a preference to magnetically align along its own [111] crystalline axis, denoted magnetocrystalline anisotropy. When a magnetic field is applied, however, it tends to pull the magnetic spins away from this preferred crystalline axis. Since the bonds that hold the magnetic spins in place to are weaker (have fewer nearest neighbor spins to interact with) close to the nanoparticle surface, the spins are more easily canted here in response to the competition between magnetic field determined Zeeman energy and the preferred magnetocrystalline anisotropy direction.

To better understand the role of magnetocrystalline anisotropy, we shall study a similar system of close packed 10 nm spherical particles of similar magnetism per volume but composed of cobalt ferrite (CoFe_2O_4) with has a 16 to 18 times higher internal magnetocrystalline anisotropy than Fe_3O_4 . Using PASANS we will be able to:

- 1) Unambiguously separate the structural scattering from the magnetic scattering
- 2) Separate the magnetic scattering into components that are “parallel to” and “perpendicular to” an external applied field
- 3) Map how the magnetic canting angle and magnitude varies as a function of field and/or temperature

References

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