Size and curvature modulation of the magnetic properties of magnetite nanoshells

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Magnetic domains in bulk materials are defined as regions in space where spin correlations establish long-range order. Their occurrence is usually dictated by the structuro-chemical properties of the materials considered, whereas their dynamics, disposition and distribution can be related to extrinsic parameters such as disorder.

As the thickness of a magnetic material is reduced, shape anisotropy effects kick into play and progressively disrupt the magnetic ordering seen in bulk. In the limit of two dimensions (2D), no magnetic ordering is allowed in isotropic systems. This is the consequence of the well-known Mermin-Wagner theorem, which prohibits long-range ordering in low dimensional systems. One possibility to re-enable order in this case is to introduce strains, or otherwise break the systems in-plane isotropy.

A viable approach to induce such a break of isotropy, while not suppressing two-dimensionality, is to impose a curvature to an otherwise flat film. In doing so, magnetic centers confined to the plane still see their immediate surroundings as flat, but are actually canted in relation to farther neighbors. Such a canting between magnetic centers is akin to the introduction of an antisymmetric spin exchange coupling to the material, whose quantum mechanical equivalent is known as the “Dzyaloshinskii-Moriya Interaction” (DMI). The strength of such an interaction has the potential to trigger different spin textures, depending on the system considered. Formally, therefore, the careful control of the substrate curvature has also the potential to introduce different spin textures into the system under consideration, provided that the curvatures involved are steep enough.

Here, we employ magnetite nano-shells surrounding a non-magnetic silica core to explore the effects of curvature-induced magnetic textures in mesoscopic systems. Through a measurement of the magnetic response of nanoparticles of different sizes, we demonstrate the effective tuning of our samples with particle diameter. Such an approach allows a selective control of the blocking temperature of our devices, as well as the induction or suppression of vortex and onion states in the material. We compare the results of the core/shell system proposed with those of bulk magnetic nanoparticles, which are often described within the framework of a core/shell structure with a superparamagnetic core and a magnetically-active shell.