Phase diagram of magnetic nanoparticles ensembles from Monte Carlo simulations in the framework of an effective macro spin model.

Abstract

Magnetic nanoparticles (MNP) present a great interest both on the fundamental point of view and for the wide range of their potential applications mainly in nanomedicine or high density recording [1]. The nanoscale manifests by the presence of a length smaller than a characteristic length scale of magnetism with the important consequence that under a critical size depending on the MNP characteristics the MNP are single domain nanocrystals whose magnetic moment may reach $\sim 10^4 \mu_b$, defining the macro-spins. A great diversity of MNP can be synthesized with well controled size and shape and organized in ordered or not superstructures starting from coloidal solutions. The leading interaction between MNP exchange uncoupled by a non-magnetic coating layer and fixed in a solid matrix after solvent evaporation is the dipole-dipole interaction (DDI) between macro spin moments. The peculiarities of the latter combined with the intrinsic magnetocrystalline anisotropy (MAE) are responsible for a set of magnetic behaviors. The latter is determined by the DDI strength (i.e. the MNP concentration in the system), the symmetry, easy-axes distribution and strength of the MAE, and the structure of the assembly. Depending on the above parameters partly tunable experimentally, one expects a magnetic phase at low temperature to be of modified *super*paramagnetic, *super*spin glass (SSG) or *super*ferromagnetic (SFM) nature. The dipolar induced SSG phase has been evidenced in numerous systems including MNP assemblies [1,2], while the SFM phase in 3D assemblies of MNP is still debated. Given the known properties of dipolar systems, and the fact that structural disorder is likely to promote a SSG state, the SFM phase is expected in long-range-ordered MNP superlattices with face-centered cubic (fcc) structure made of MNP with either small MAE to DDI strengths ratio in the case of random easy axes distribution or with textured distribution of MAE easy axes.

In this presentation, after a brief overview of the topic we present Monte Carlo simulations aimed at model an actual experimental situation, namely the magnetic phases of well ordered superlattices made of either Co or γFe_2O_3. The model considered is the simplest effective macro-spin model, namely a monodisperse ensemble of dipolar hard spheres located on the nodes of a fcc lattice, with uniaxial MAE.

We focus on the characterization of the low temperature phase of the system and consequently on the conditions under which the SFM can be obtained in the framework of the finite size scaling. The SFM state is evidenced from the spontaneous magnetization $< m >$ and the Binder cumulant B_m while the spin-glass state (SSG) is evidenced from the overlap spin-glass order parameter and the corresponding Binder cumulant B_q or the spin glass correlation length. The results are discussed with respect to the the disorder control variable which is either the amplitude of the MAE or the variance of the easy axes orientational distribution.

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Work performed under grant ANR-CE08-007 from the ANR French Agency.