Magnetic structures and excitations of 3D nanoparticles

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Magnetic nanoparticles are produced for memory applications as well as for biomedical applications since they can be driven or stirred by external magnetic fields. Networks of nanoparticles evidenced interesting spectra of excitations opening the way to materials with a low index such as metamaterials. The magnetic structures and excitations of 3D nanoparticles are rather badly known because of the occurrence of long ranged coupling such as dipolar interaction which competes with local interactions such as an exchange. The goal of this paper is to introduce a systematic view of these magnetic structures and excitations for different materials and samples. The characteristic parameter is the ratio between dipolar interaction and exchange. This effective ratio evolves with both materials and sample size. The results of Langevin numerical analysis of both structures and excitations of a 64*64*64 cube show a set of transitions from a uniform domain structure to a final multidomain structure where singularity lines design a full 3D network as shown in the figure, a snapshot of an actual movie. Among the steps: a single vortex (or antivortex) line, the occurrence of a 2D network of vortex lines. As expected in such small samples super-paramagnetism occurs and there is a rather slow dancing collective motion of these singularity lines. These rather localized collective motions generalize the gyrotropic vortex motion of a 2D nanoparticle. The low-frequency excitations are directly obtained from Langevin simulations while higher energy excitations are derived from the dynamical matrix approximation, evidencing gaps in the spectrum. The low energy spectrum shows a critical behavior of the super-paramagnetism blocking time. These behaviors would be modulated by the addition of extra interactions such as anisotropy and Dzyaloshinskii-Moriya interaction for instance with the introduction of skyrmions

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