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Energy landscapes and relaxation dynamics in ensembles of magnetic nanoparticles: Disorder-driven transition from good-folding to spin-glass behavior

G. M. Pastor, Institute of Theoretical Physics, University of Kassel, Germany

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Información sobre el evento: Eduardo Bringa (ebringa@yahoo.com)

Resumen

Nanostructured materials are often composed of ensembles of atomic clusters and small particles, whose structural arrangement is unavoidably subject to some degree of disorder. Understanding the role of disorder on the physical behavior of nanoscale systems is central to material design, particularly in the context of magnetism.

The main purpose of this talk is to report recent theoretical investigations of the static and dynamic properties of two-dimensional ensembles of dipole-coupled magnetic nanoparticles (NPs). Particular emphasis is given to the correlations between the geometrical arrangements of the NPs, their inherent structural disorder, and the cooperative magnetic dynamics of the nanostructures as a whole. To this aim, representative two-dimensional NP ensembles with different structural geometries and degrees of disorder are considered. The interaction-energy landscapes (ELs) of the ensembles are characterized and analyzed systematically by calculating the local minima and connecting first-order saddle points and by deriving the corresponding disconnectivity graphs and kinetic networks.

The study shows that the topology of the ELs changes as a function of disorder in a most profound way. Weakly disordered square and triangular ensembles are found to be good structure seekers with a relaxation dynamics that is funneled towards the ground state. In contrast, the ELs of strongly disordered ensembles are very rough, with a much larger number of low-energy local minima. These are separated by large energy barriers which increase as the energy of the metastable states decreases. The consequences on the magnetic response are dramatic. While the relaxation dynamics in weakly disordered square and triangular ensembles follows a stretched exponential law with a single characteristic time scale, strongly disordered ensembles show a much more intricate dynamics that includes nontrivial phenomena such as multiple time scales, trapping and possibly ergodicity breaking. A microscopic understanding of the dominant relaxation processes, their interrelations and the resulting dynamics is achieved. The possibility of manipulating the cooperative magnetic behavior of NP ensembles by applying external magnetic fields is discussed. Finally, some of the goals and limitations of present approach are explored by comparing it with the predictions of the Landau-Lifshitz-Gilbert equation.