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First-order reversal curves: a powerful characterization technique for magnetic nanostructures

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Abstract – In order to test the accuracy of the first-order reversal curve (FORC) technique for magnetic nanostructures, we measured and analyzed FORC results from various simple systems of interacting nanoparticles, both experimentally and by simulation. The systems consist of crystalline Fe_3O_4 nanoparticles with a narrow size distribution, uniformly dispersed in a polymer matrix. Both the size (diameter = 5 – 100 nm) and the interparticle distance were varied. The results obtained show that the FORC technique permits to quantification of the coercivity distribution of the individual nanoparticles, and dipolar interaction field distribution.

The field of magnetic nanostructures is evolving rapidly in response to the needs of industry (magnetic data storage, biomedical applications etc.). Dipolar interactions, which become more important as the pitch decreases, modify the overall properties of such systems, compared to those of the individual magnetic entities. In this context, an experimental technique able to characterize the distribution of the magnetostatic properties of the entities making up the system entities constitutes an increasingly valuable tool.

The first-order reversal curve (FORC) technique [1] is a promising candidate for this purpose. However, its use is usually not based on physical principles, but rather on abstract mathematical objects, called hysterons, and includes only indirectly the concept of interaction between them. The goal of this work is to test the quantitative accuracy of the experimental application of the FORC technique to weakly interacting systems.

Crystalline Fe_3O_4 nanoparticles of various sizes (diameter = 5 – 100 nm) were synthesized using a chemical procedure [2], which has been optimized to provide a narrow size distribution. The nanoparticles were then uniformly dispersed in a highly viscous polymer. Samples contained one or two size distributions, in a range of concentrations in order to vary the dipolar interactions between the nanoparticles. For each system, the first-order reversal curves were both measured experimentally, at 5 K (in order to avoid reversible changes due to paramagnetic nanoparticles), and simulated by using physically meaningful hysterons [3].

Good agreement between the experimental and simulated FORC results demonstrates the accuracy of the FORC method for characterizing weakly interacting systems. For measurements below the blocking temperature of the system, the average nanoparticle coercivity and the dipolar interaction field distribution of each size distribution can be directly extracted from the FORC result. The precision of the coercive field and interaction field distributions is directly linked to the experiment parameters: applied field step, reversal field step and interpolation area used for the FORC result calculation. Experimentally, this precision appears to be limited by noise present in the moment measurement, and by measurement time.

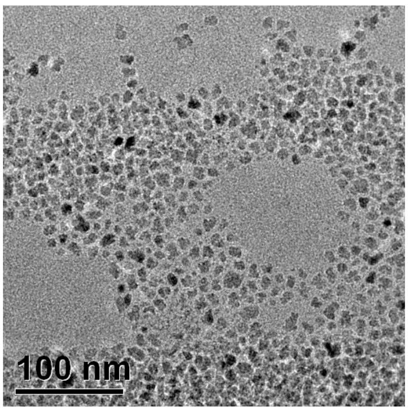

Figure 1: TEM image of the Fe_3O_4 nanoparticles.

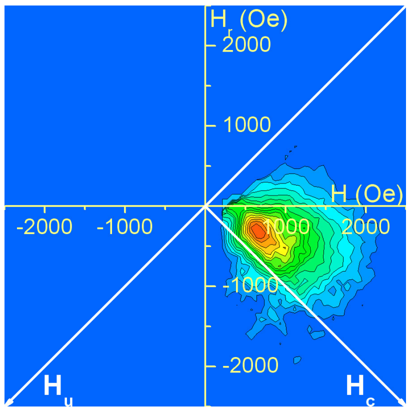

Figure 2: Typical experimental FORC result for dispersed nanoparticles.

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