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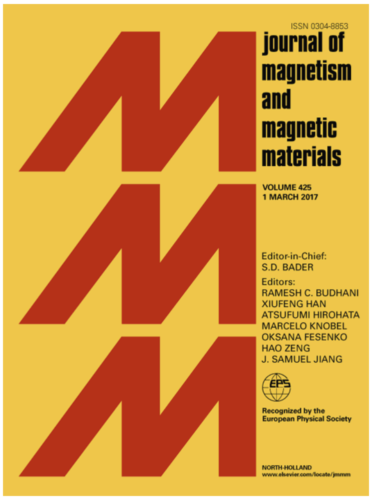

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A Phenomenological approach to study the effect of uniaxial anisotropy on the magnetization of ferromagnetic nanoparticles

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Abstract

We study the effect of the uniaxial anisotropy in a system of ideal, noninteracting ferromagnetic nanoparticles by means of a thermodynamical model. We show that the effect of the anisotropy can be easily assimilated in a temperature shift T_a^*, in analogy to what was proposed by Allia et al. [1] in the case of interacting nanomagnets. The phenomenological anisotropic T_a^* parameter can be negative, indicating an antiferromagnetic-like behavior, or positive, indicating a ferromagnetic-like character as seen in the inverse susceptibility behavior as a function of temperature. The study is done considering an easy axis distribution to take into account the anisotropy axis dispersion in real samples (texture). In the case of a volumetric uniform distribution of anisotropy axes, the net effect makes T_a^* to vanish, and the magnetic susceptibility behaves like a conventional superparamagnetic system, whereas in the others a finite value is obtained for T_a^*. When magnetic moment distribution is considered, the effect is to enhance the T_a^* parameter, when the dispersion of the magnetic moments becomes wider.

Keywords: Magnetic Anisotropy, Ferromagnetic Nanoparticles, Magnetic Susceptibility, Langevin function.

1. Introduction

The interest for studying magnetic nanoparticles, from the fundamental as well as technological point of view, has been continuously growing over the last years, mainly owing to potential applications in diverse areas such as hyperthermia, drug delivery and data storage, among others [2, 3].

Experimental studies as well as theoretical models are required in order to precisely control and determine the macroscopic properties of such nanosystems. This allows one to properly design systems with specific functionalities, as required in each different application [4, 5, 6]. In the process of understanding of granular magnetic systems, there are still many requirements to be considered and explained by means of models that reconcile the experimental findings with theory.

In the early 2000, Allia et al. [1] proposed a phenomenological model where the effects of dipolar interactions among the nanoparticles were taken into account by means of a fictitious temperature named “phenomenological temperature” or T^*. In their work they modified the classical expression of the Langevin function by means of this phenomenological temperature, by adding it to the actual temperature and so describing fairly well the magnetic moment of granular systems of $\mathrm{Cu}_{90}\mathrm{Co}_{10}$. By this simple way, they overcame some contradictions and difficulties found in some experimental data, and not explained up to that time by other models [1]. The application of the T^* model to granular solids represents a straightforward way to extend the classical Langevin model. This happens mainly for the following reasons: a) It allows, in very simple way, from the mathematical viewpoint, to explain the experimental data for these systems; b) it allows to conciliate the discrepancies or contradictions that appear when magnetic moments are infered from magnetic and structural measurements; and c) it allows to draw a phase diagram regarding the different regimes on nanomagnetic systems (B_S, single-particle blocked regime; B_C, collective blocked regime; ISP, interacting superparamagnetic regime; SP, superparamagnetic regime).

The phenomenological temperature model of Allia has been also used in several other magnetic systems [7, 8, 9, 10] and also has been improved using mean field models [11].

However, although the model is appropriate in certain situations and has been extensively applied, its complete validity has been questioned by some authors by means of Monte Carlo simulations [12]. Indeed, at low temperatures the simple description by means of the T^* model is not complete, because in the low temperature region there are effects of spatial ordering and the coexistence of anisotropy and dipole-dipole interaction. In any system with non-neglegible anisotropy it must affect the reorientation freedom of the magnetic moments in a different way that a simple, classical Langevin function can reproduce. This occurs because the Langevin function is independent of positional order and it does not consider any anisotropy. On the other hand, it has been reported that the anisotropy generates a region or magnetic state coined “anisotropic superparamagnetism” (ASP) in a temperature region above the blocking temperature [13], in this region the magnetization curves at a given temperature clearly distinguish from the Langevin curves at the