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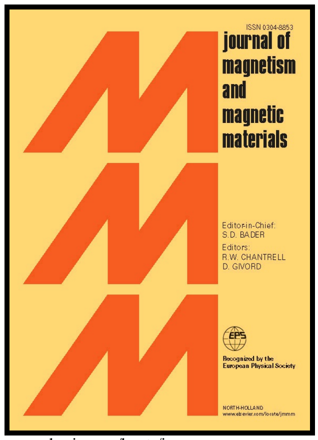

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PII: S0304-8853(16)33139-0
DOI: http://dx.doi.org/10.1016/j.jmmm.2016.12.046
Reference: MAGMA62254

To appear in: *Journal of Magnetism and Magnetic Materials*

Received date: 21 November 2016
Revised date: 28 November 2016
Accepted date: 18 December 2016

Cite this article as: Balaev, S.V. Semenov, A.A. Dubrovskiy, S.S. Yakushkin, V.L. Kirillov and O.N. Martyanov, Superparamagnetic Blocking of an Ensemble of Magnetite Nanoparticles upon Interparticle Interactions, *Journal of Magnetisn and Magnetic Materials,* http://dx.doi.org/10.1016/j.jmmm.2016.12.046

Superparamagnetic Blocking of an Ensemble of Magnetite Nanoparticles upon Interparticle Interactions

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Abstract—We report on the effect of interparticle magnetic interactions in an ensemble of superparamagnetic magnetite particles with an average size of ~8.4 nm dispersed in the diamagnetic matrix on the blocking of this ensemble in external magnetic field. The two limit cases are investigated: the case of strongly interacting particles, when the value of magnetic dipole-dipole interaction between particles is comparable with the energy of other interactions in the ensemble (the interparticle distance is similar to the nanoparticle diameter) and the case of almost noninteracting particles distant from each other by about ten particle diameters. We demonstrate that the experimental dependence of the blocking temperature on external field is described well within the model [1], in which the density of particles in a nonmagnetic medium is taken into account and the correlation value depends on external magnetic field. The model for describing the magnetic properties of a disperse nanoparticle ensemble is proposed, which makes corrections related to the particle size and mean dipole-dipole interaction energy for the anisotropy constant. The surface magnetic anisotropy of Fe_3O_4 particles and parameters of the interparticle coupling are estimated.

Keywords: Fe_3O_4 nanoparticles; superparamagnetic nanoparticles; size effect; blocking temperature.

1. Introduction

The range of possible applications of magnetic nanoparticles has been permanently broadening and currently involves biomedicine (drug transport, diagnostics, imprinted polymers, and hyperthermia) [2] high-density magnetic memory [3–7], catalysis [8–10], etc.

In the overwhelming majority of the problems to be solved, researches and engineers deal not with isolated particles, but with their ensembles. Therefore, along with the fundamental problem of forming nanoparticles of specified sizes, surface properties, and magnetic characteristics, there exists the equally important problem that concerns the effect of interparticle magnetic interactions on the magnetic properties of ensembles of interacting particles [11–14]. The magnetic interparticle interactions can significantly change the magnetization, coercivity, and other magnetic characteristics of an ensemble and give rise to various effects, which are not averaged even over a sufficiently large ensemble of magnetic particles [15–17] Thus, when describing the magnetic properties of interacting nanoparticles, even with taking account for only dipole-dipole interactions, we should consider not only the standard characteristics (volume and surface magnetic anisotropy, size distribution of particles, and temperature of the transition to the blocked state), but also parameters of the interaction between magnetic particles [1,18–22].

In particular, an urgent problem is the transition of an ensemble of single-domain superparamagnetic nanoparticles to the so-called blocked state upon magnetic coupling between them. The temperature T_B of superparamagnetic blocking of noninteracting particles is determined using the well-known Neel–Brown formula