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Research paper

EPR detection of presumable quantum behavior of iron oxide nanoparticles in dendrimeric nanocomposite

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ABSTRACT

The superparamagnetic γ-Fe_2O_3 nanoparticles (average diameter of 2.5 nm) encapsulated in poly(propylene imine) dendrimer have been investigated by Electron Magnetic Resonance (EMR). EMR measurements have been recorded in perpendicular and parallel configurations in the wide temperature range (4.2–300 K). It has been shown that the model based on the spin value $S = 30$, corresponding to the total magnetic moment of the nanoparticle, can be used to interpret the experimental results and the proof of the quantum behavior of γ-Fe_2O_3 nanoparticles.

1. Introduction

Recently, interest in the study of nanoscale magnetic systems has increased significantly, which is caused by both wide technological applications of such systems (catalysis [1] storage [2], spintronics [3], MRI [4], magnetic fluids [5], biotechnology and biomedicine [6,7]), and fundamental scientific interest [8,9]. In the world of nanoscale magnetic systems, two classes of such objects can be distinguished: magnetic nanoparticles (NP_S) and molecular nanomagnets (MNMs). The behavior of MNMs is known to be described by quantum mechanics, where calculations begin by considering the behavior of a single ion, while NPs behavior is described in terms of classical physics on the basis of parameters obtained for bulk materials. It seems interesting to develop a common approach for the consideration of nanoscale magnetic systems, which could provide a better understanding of their properties. Electron magnetic resonance (EMR) is an excellent tool to demonstrate the similarities in the behavior of NPs and MNMs, and its use can provide experimental evidences of quantum behavior of single-domain NPs. Some evidences in favor of the discrete nature of spin levels of NPs are already known in the literature. For example, a small signal is observed in the half-field of EMR spectra [10–13], which, according to some authors, is attributed to forbidden transitions between states with $\Delta m = \pm 2$. Its appearance is interpreted as a proof of the quantum nature of the system and in such approach a nanoparticle is considered to be a giant exchange-coupled cluster with a total spin S.

In this paper, we try to find the quantum nature of ultrafine γ-Fe_2O_3 NPs encapsulated into dendrimeric matrix and for this purpose we offer to use the approach proposed in [14] – to record EMR spectra of NPs in both (parallel and perpendicular) configurations, that is, when the H_1 field of the microwave radiation is parallel or perpendicular to the external magnetic H_0 field. These alternative configurations have different selection rules for the allowed transitions between the total spin projections, and therefore, provide the opportunity to "feel" the quantum nature of the system.

2. Results and discussion

In our previous paper [15], we investigated by EMR spectroscopy the behavior of superparamagnetic single-domain γ-Fe_2O_3 NPs (average diameter of 2.5 nm) encapsulated in poly (propylene imine) dendrimer of the second generation (Fig. 1), using the classical theoretical approach [16]. The typical EMR spectra (for configuration $H_1 \perp H_0$) are shown in Fig. 2. As we can see, one basic signal with g- factor 2 is observed, which becomes

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