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Estimation of particle magnetic moment distribution for antiferromagnetic ferrihydrite nanoparticles

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ABSTRACT

Magnetization as a function of applied magnetic field at different temperatures for antiferromagnetic nanoparticles of ferrihydrite is measured and analyzed considering a distribution in particle magnetic moment. We find that the magnetization of this nanoparticle system is affected by the presence of particle magnetic moment distribution. This particle magnetic moment distribution is estimated at different temperatures.

1. Introduction

People have been working on small particles of magnetic materials for last several decades due to their potential applications and interesting behavior [1–3]. One of the properties that makes the magnetic nanoparticles unique is superparamagnetism. Sufficiently small particles of ferro and ferrimagnetic materials are expected to show the superparamagnetic behavior [2]. Long back Néel suggested that small particles of antiferromagnetic materials should also exhibit magnetic properties such as superparamagnetism [3]. The magnetization of a bulk antiferromagnetic crystal is expected to be zero in absence of any external magnetic field at 0 K. However if the surface to volume ratio, which increases with decreasing particle size, for an antiferromagnetic particle is made sufficiently large then it can have a nonzero net magnetic moment due to an imperfect cancellation of atomic moments near the surface of the particle. A lot of work have been reported on the magnetic behavior of small particles of ferro and ferrimagnetic materials. Nanoparticles of antiferromagnetic materials have also gained sufficient attention from researchers mainly due to surprising and unusual behavior exhibited by them. Among different antiferromagnetic nanoparticle systems, NiO [4–9], ferritin [10–12] and ferrihydrite [13–17] are comparatively more interesting and well-studied systems.

The magnetization of ferro and ferrimagnetic nanoparticles can be described by the Langevin function [2]. However the magnetization of antiferromagnetic nanoparticles can not be described by this function. In fact, it can be described by an altered form, known as the modified Langevin function, of this function [6,10,11,13]. People have been using the modified Langevin function to estimate the value of particle magnetic moment. Fitting the magnetization data of 5 nm NiO particles to the modified Langevin function gives a value of about 2000 μ_B for the particle magnetic moment [6,7]. Such values for the particle magnetic moment are very large in comparison to the expected values. Any real sample of nanoparticles always has some distribution in particle size. This particle size distribution gives rise to a particle magnetic moment distribution for a system of magnetic nanoparticles. Recently, it has been shown that the ignorance of the particle magnetic moment distribution is the reason for the strange behavior of NiO nanoparticles [18]. Reasonable value of about few hundred Bohr magnetons for the particle magnetic moments is obtained, if the modified Langevin function is used to fit the magnetization data considering a distribution in the particle magnetic moment for 5 nm NiO particles. However, it is still not clearly understood whether this observation is a characteristic of NiO nanoparticles only or a general behavior applicable for all magnetic nanoparticle systems. For this the effect of particle magnetic moment distribution on the magnetization of few more nanoparticle systems should be studied. This motivated us to study the effect of particle magnetic moment distribution on the magnetization of antiferromagnetic ferrihydrite nanoparticles. During this study the particle magnetic moment distribution in a sample of 2 nm ferrihydrite particles is estimated.

Ferrihydrite is a nanocrystalline material and found in nature in

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many environmental [19] and biological systems [20]. Researchers have also synthesized few forms of this material by suitable chemical routes. Depending on the number of peaks in X-ray diffraction, it is named as two lines and six lines ferrihydrite [21]. Researchers in different disciplines of science have been working on natural and synthetic ferrihydrite. Its disputed structure [21] and interesting magnetic behavior [13,14,16] have been attracting the attention of physicists. Ferrihydrite is known to be antiferromagnetic in nature having Néel temperature of about 350 K [13]. Magnetic behavior of undoped and doped ferrihydrite nanoparticles are reported in the literature in details [13,16]. However in these works the role of the particle magnetic moment distribution was not studied. In this work we present the magnetization measurements on 2 nm ferrihydrite particles. We analyze the data using the modified Langevin function first without considering any distribution and then considering a distribution in the particle magnetic moment.

2. Experimental details

Ferrihydrite nanoparticles are synthesized by a chemical method by reacting in aqueous solution ferric nitrate and sodium hydroxide at room temperature as described elsewhere [21]. We use iron (III) nitrate nonahydrate, sodium hydroxide pellets, both from Aldrich, and triple distilled water. The procedure is as follows. In a 0.2 M clear brown solution of iron (III) nitrate, a 1 M transparent solution of sodium hydroxide is added drop wise while continuously stirring at room temperature until pH of the system reaches 7.5. The resulting precipitate is washed several times with distilled water, dried at 60 °C overnight and ground to get brown colored powder sample. This powder sample is used for all further characterizations.

3. Results and discussion

3.1. Structural characterization

Room temperature X-ray diffraction data, of the synthesized powder sample, are collected using a PANalytical diffractometer and Cu K $_\alpha$ radiation. This diffraction pattern is shown in Fig. 1(a). From this figure we find that the synthesized brown colored powder sample is single phase 2 lines ferrihydrite [13]. This figure also shows that the peaks are very broad. The average crystallite size is calculated by X-ray diffraction line broadening using the modified Scherrer formula [8,22,23]. It turns out to be about 2 nm. The powder sample is also characterized with a FEI Tecnai transmission electron microscope. The transmission electron micrograph is shown in Fig. 1(b). This micrograph shows that particles are of different shapes and sizes. Selected area electron diffraction pattern from the particles is shown in Fig. 1(c). Two rings in this pattern correspond to the two diffraction peaks in the X-ray diffraction pattern. From Fig. 1(b) the mean particle size turns out to be about 2.6 nm with a standard deviation of 0.9 nm. Clearly the mean particle size determined by the transmission electron micrograph is close to the average crystallite size determined by the X-ray diffraction. It means that on an average each nanoparticle is a crystallite. Fig. 1(d) shows statistical distribution of particle sizes. This distribution, based on the size measurements of about 160

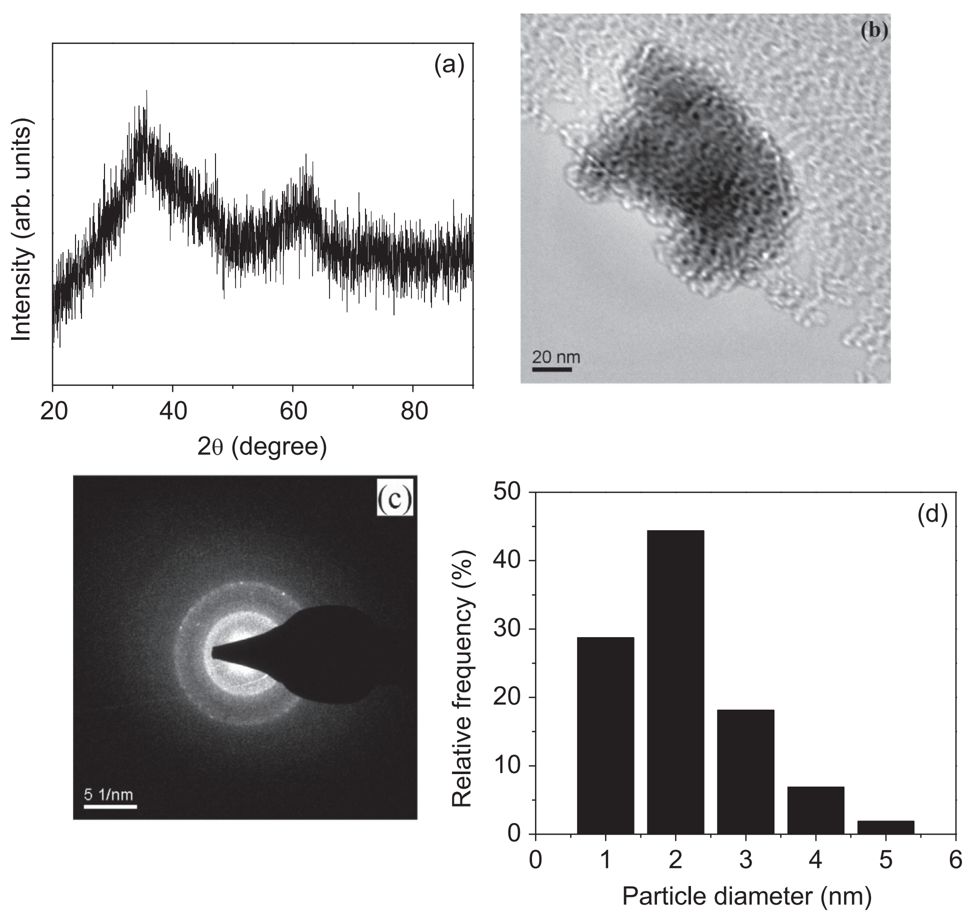

Fig. 1. (a) Room temperature X-ray diffraction pattern of the sample, (b) transmission electron micrograph of the sample, (c) selected area electron diffraction pattern and (d) a histogram of the distribution of particle sizes.