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Role of particle size distribution and magnetic anisotropy on magnetization of antiferromagnetic nanoparticles

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ABSTRACT

Magnetization measurements on antiferromagnetic iron storage protein ferritin are reported. The magnetization as a function of applied magnetic field data in superparamagnetic region are analyzed considering a distribution in particle size. The estimated particle size distribution is compared with that determined from transmission electron micrograph. Effect of magnetic anisotropy on magnetization process of this nanoparticle system is also discussed.

1. Introduction

Behavior of small particles of magnetic materials has been under attraction since the days of Néel and Brown [1,2]. Researchers from different disciplines of science and engineering have been working on such systems because of interesting behavior [3,5] and useful applications [6,7]. For physicists, particularly, the attraction for these materials is due to unusual, unique and interesting behavior exhibited by them. Behavior such as superparamagnetism is only shown by these systems. This phenomenon is observed when thermal energy becomes much larger than the anisotropy energy of particles. However, superparamagnetism has also been reported in submillimetre sized magnetite porous single crystals in a recent work [4]. Here lattice defects caused by stress-strain are claimed to be responsible for this observation. For antiferromagnetic particles, particularly, the anisotropy energy signifies the energy required to change the direction of all spins by 180° [3].

Magnetization of magnetic nanoparticles is affected by several factors. Particle magnetic moment distribution is one such important factor [8]. This distribution arises due to distribution in particle size and shape. We studied the effect of particle magnetic moment distribution on magnetization process of antiferromagnetic nanoparticle systems. For NiO nanoparticles, we showed that ignorance of this particle magnetic moment distribution is reason for reported unusual behavior of this system [9]. This distribution can be estimated by fitting the magnetization as a function of applied magnetic field data in superparamagnetic region to appropriate expression [10]. The dependence of particle magnetic moment distribution on magnetization can also be used to estimate concentration of individual magnetic component present in nanocomposites [11]. Magnetic anisotropy is well known to affect the magnetization of magnetic materials [12–15]. But simultaneous effect of particle size distribution and magnetic anisotropy on magnetization process of nanoparticle systems is never studied. This motivated us to work on this important issue.

Ferritin is an iron storage protein found in blood of mammals [16]. It stores iron in body in a nontoxic form. This material is antiferromagnetic in nature [17–19]. It has a core-shell structure. The core is about 8 nm in diameter surrounded by a 2 nm thick protein shell [20]. This protein shell reduces the strength of dipolar interaction among particles. Because of this reason the ferritin is considered to be a model superparamagnet [21]. In this work we present analysis of magnetization data on ferritin considering effect of particle size distribution and magnetic anisotropy.

2. Experimental details

Ferritin from equine spleen is obtained from Sigma-Aldrich Corporation, USA. It is supplied in form of a suspension in saline solution. One drop of well diluted suspension is allowed to dry on a carbon coated copper grid for transmission electron microscopy. The original suspension is dried under vacuum. The dried flakes are ground to get fine powder sample. This powder sample is used for magnetization measurement.

3. Results and discussion

3.1. Particle size

Ferritin is characterized with a FEI Tecnai transmission electron

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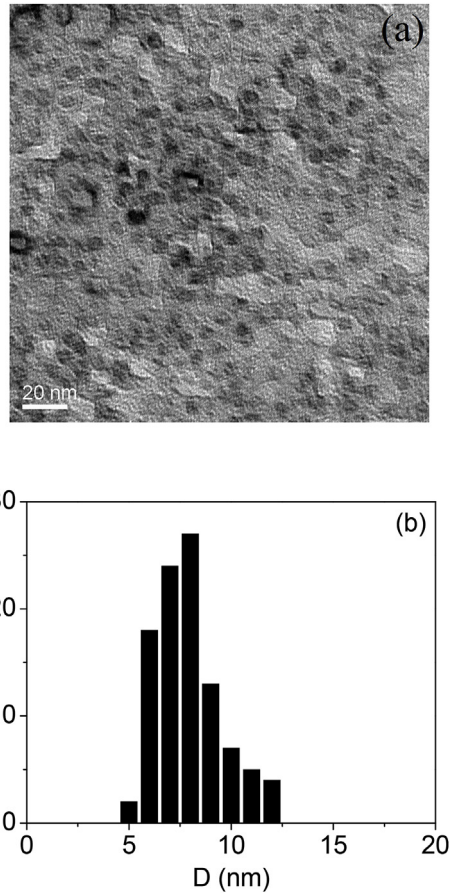

Fig. 1. (a) Transmission electron micrograph and (b) histogram of distribution of particle diameter D for ferritin.

microscope. Fig. 1 (a) shows the transmission electron micrograph. This micrograph shows the dense inorganic cores only [22]. From this micrograph we see that the particles are almost spherical in shape. Fig. 1(b) shows histogram for statistical distribution of particles diameter D. This distribution is based on size measurement of 100 particles. It peaks at 8 nm. The arithmetic mean of particle size is found to be 8.4 nm with a standard deviation of 1.6 nm.

4. Magnetization

4.1. Temperature dependence

Magnetization of ferritin is measured using a commercial vibrating sample magnetometer (Quantum Design, PPMS). Fig. 2 shows zero field cooled (ZFC) and field cooled (FC) susceptibility χ as a function of temperature T in 250 G applied magnetic field for ferritin. This figure shows that the ZFC and FC curves bifurcate at temperature $T_{bf} \approx 17$ K. We also see a peak in the ZFC curve near this temperature. However the FC susceptibility is seen to decrease monotonically with increasing temperature. These are characteristics of a superparamagnetic system.

4.2. Field dependence

We measure magnetization of ferritin as a function of applied magnetic field. Fig. 3 shows M-B loops at 5 and 300 K. The data at 5 K shows a hysteresis. This temperature is below the bifurcation temperature T_{bf}. In this region the magnetization relaxes slowly and so we see a hysteresis in the M-B loop. The system is in superparamagnetic state above the bifurcation temperature T_{bf}. In this region the magnetization relaxation is extremely fast and so we do not see any hysteresis

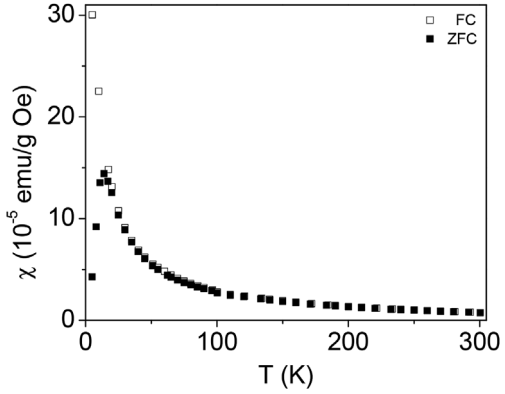

Fig. 2. ZFC (solid symbol) and FC (open symbol) susceptibility χ as a function of temperature T for ferritin in 250 G applied magnetic field.

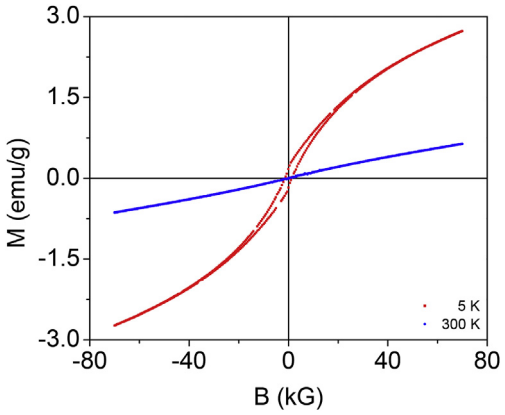

Fig. 3. M-B loops for ferritin at 5 and 300 K.

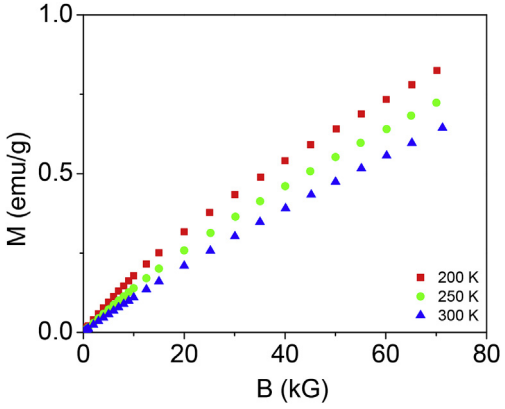

Fig. 4. Magnetization M as a function of applied magnetic field B for ferritin at different temperatures.

in the M-B loop. Because of this reason there is no hysteresis at 300 K.

Fig. 4 shows magnetization M as a function of applied magnetic field B for ferritin at different temperatures in superparamagnetic region. We see that the magnetization increases with increasing strength of applied magnetic field. At higher magnetic fields, specially, the magnetization increases almost linearly with applied field. The magnetization is also seen to decrease with increasing temperature. These observations are as per expectation for antiferromagnetic nanoparticle systems in superparamagnetic region [17].