Calculating effective magnetocrystalline anisotropy from ZFC/FC measurements on cobalt ferrite/nickel ferrite core-shell nanoparticles

*Sara L. FitzGerald, Zichun Yan, Karen Livesey, Thompson Mefford, Thomas M. Crawford
PhD Candidate, University of South Carolina, PhD Student, Clemson University, Associate Professor, University of Colorado, Colorado Springs, Associate Professor, Clemson University, and Professor, University of South Carolina

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Introduction: We will present zero field-cooled/field-cooled measurements (ZFC/FC) performed on cobalt ferrite/nickel ferrite core shell nanoparticles. The nanoparticles are synthesized in two steps: 1) synthesis of oleate precursors, and 2) continuous injection synthesis of particles [1]. To obtain a core-shell structure, cobalt and nickel precursor solutions are mixed separately with iron precursor solutions in a volume ratio of 1:2, respectively, to give a cobalt ferrite precursor solution and a nickel ferrite precursor solution. The cobalt ferrite and nickel ferrite precursors are injected for different amounts of time to control the core and shell thicknesses. Nanoparticle sizes are determined by TEM image analysis giving a mean diameter of 10 nm and standard deviation of 1 nm.

Methodology: From the inflection point of the ZFC branch of the data shown in Fig. 1 [2], we obtain a mode blocking temperature of 154 K. In addition, we find the interaction temperature by measuring moment versus field at various temperatures greater than T_B [3]. Fitting the inverse susceptibility vs. temperature curve, at high temperatures only, using the Curie-Weiss law (Fig. 2), we find an interaction temperature, T_0 = -93 K. The negative interaction temperature and the shape of the $1/\chi$ curve, suggest that the interaction opposes the external field in some way [4]. Data at higher temperatures are needed to further confirm that the spin interactions within the nanoparticles or interactions between nanoparticles follow the Curie-Weiss law.

Conclusion: Using T_0 in conjunction with T_B, we obtain a value for the effective anisotropy of approximately Keff = 100 kJ/ m^3 [5]. The anisotropy for bulk cobalt ferrite is 180–300 kJ/m^3 [6] while for nickel ferrite it is 11 kJ/ m^3 [7]. Thus, the calculated effective anisotropy is between that of bulk cobalt ferrite and bulk nickel ferrite.

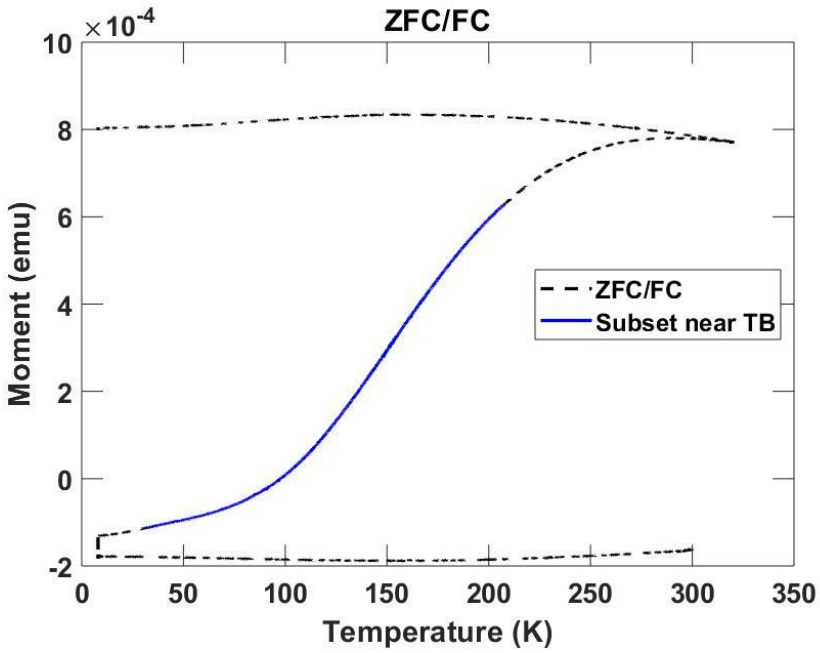

Fig. 1 ZFC/FC moment signal over the temperature range 300 K to 8 K.

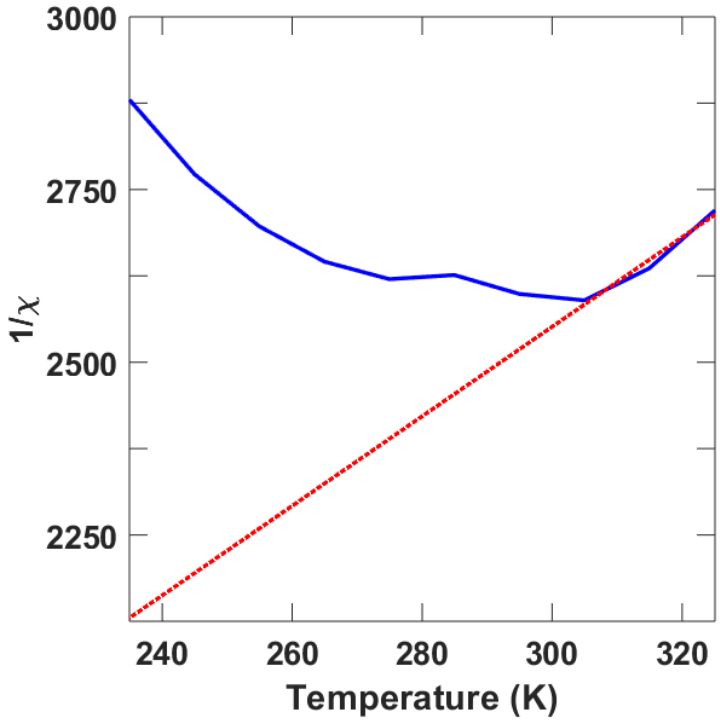

Fig. 2 Inverse susceptibility plotted versus temperature (blue solid line). The Curie-Weiss Law fit (red dashed line) of data above the turning point intersects the temperature axis at the interaction temperature, T_0.

References: [1] Vreeland EC, Watt J, Schober GB, Hance BG, Austin MJ, Price AD, Fellows BD, Monson TC, Hudak NS, Maldonado-Camargo L, Bohorquez AC. Enhanced nanoparticle size control by extending LaMer's mechanism. Chemistry of Materials. 2015 Aug 21;27(17):6059-66.

[2] I. J. Bruvera, P. Mendoza Zelis, M. Pilar Calatayud, G. F. Goya, and F. H. Sanchez, "Determination of the blocking temperature of magnetic nanoparticles: The good, the bad, and the ugly," Journal of Applied Physics, vol. 118, pp. 184304, 2015.

[3] L. Maldonado-Camargo, M. Unni, & C. Rinaldi, "Magnetic characterization of iron oxide nanoparticles for biomedical applications", Chpt. 4 in Biomedical Nanotechnology: Methods and Protocols. Eds S. Hurst Petrosko and E. S. Day (Humana Press, New York, 2017).

[4] B. D. Culity and C. D. Graham, Chpt. 5 in Introduction to Magnetic Materials, 2nd ed. (John Wiley & Sons, Inc., New Jersey, 2009).

[5] K. L. Livesey, S. Ruta, N. R. Anderson, D. Baldomir, R. W. Chantrell, and D. Serantes, "Beyond the blocking model to fit nanoparticle ZFC/FC magnetisation curves," Nature Scientific Reports, vol. 8, article number: 11166, 2018.

[6] L. D. Tung, V. Kolesnichenko, D. Caruntu, N. H. Chou, C. J. O'Connor, and L. Spinu, "Magnetic properties of ultrafine cobalt ferrite particles", Journal of Applied Physics, vol. 93, pp. 7486 2003.

[7] E. C. Sousa, M. H. Sousa, G. F. Goya, H. R. Rechenberg, M. C. F. L. Lara, F. A. Tourinhob, J. Depeyrot, "Enhanced surface anisotropy evidenced by Mössbauer spectroscopy in nickel ferrite nanoparticles," Journal of Magnetism and Magnetic Materials, vol. 272–276, Supplement, pp. E1215-E1217, 2004.