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Uncertainty Analyses of Static Measurements of Induced Magnetisation

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Abstract

Magnetic nanoparticles (MNP) have a wide range of application. They are used for instance as contrast agent for magnetic resonance imaging, as drug delivery vehicle, for magnetic hyperthermia, for sewage treatment, as ink for bank notes, in high-quality loudspeakers or for research purposes. The demand for custom tailored MNPs fosters the development of new MNPs with specific biological and physical properties. Accurate and precise magnetic property characterisation is thus required for quality control of newly developed MNPs at laboratory scales but also for optimising scale-up production procedures, i.e., the production of MNPs in commercial quantities. International standards for definition and measurement of the magnetic properties of MNPs do not exist. This reduces the trust of magnetic nanoparticle consumers in safety, reliability and functionality of magnetic nanoparticle products and increasingly hampers the market chances of magnetic nanoparticle producers.

Internal and external sources of uncertainty of induced magnetisation curves will be analysed and their consequences on the uncertainty of corresponding parameters discussed, i.e., saturation magnetisation, saturation remanence, coercive force and as well as low and high-field susceptibility. Example measurements performed with a Magnetic Property Measurement System will be presented for the calibration standard, natural samples, artificial MNP powders and MNP suspensions. The example below refers to two different magnetic nanoparticle samples. One consists of $\geq \approx 150$ nm magnetite (Fe_3O_4) particles and the other of maghaemite (γ-Fe_2O_3) particles with a size of 34 nm. In order to detect possible sources of uncertainty, four different sub-samples were made from each of the two samples. Uncertainty analysis reveals that the actual measured values, i.e., the magnetic moments are not affected by large uncertainties. For individual subsamples they range between 0.001 and 0.009%. However, the standard deviation of the mean M_s of the four sub-samples is much larger, i.e., between 2 and 4% for magnetite and maghaemite, respectively. The uncertainty

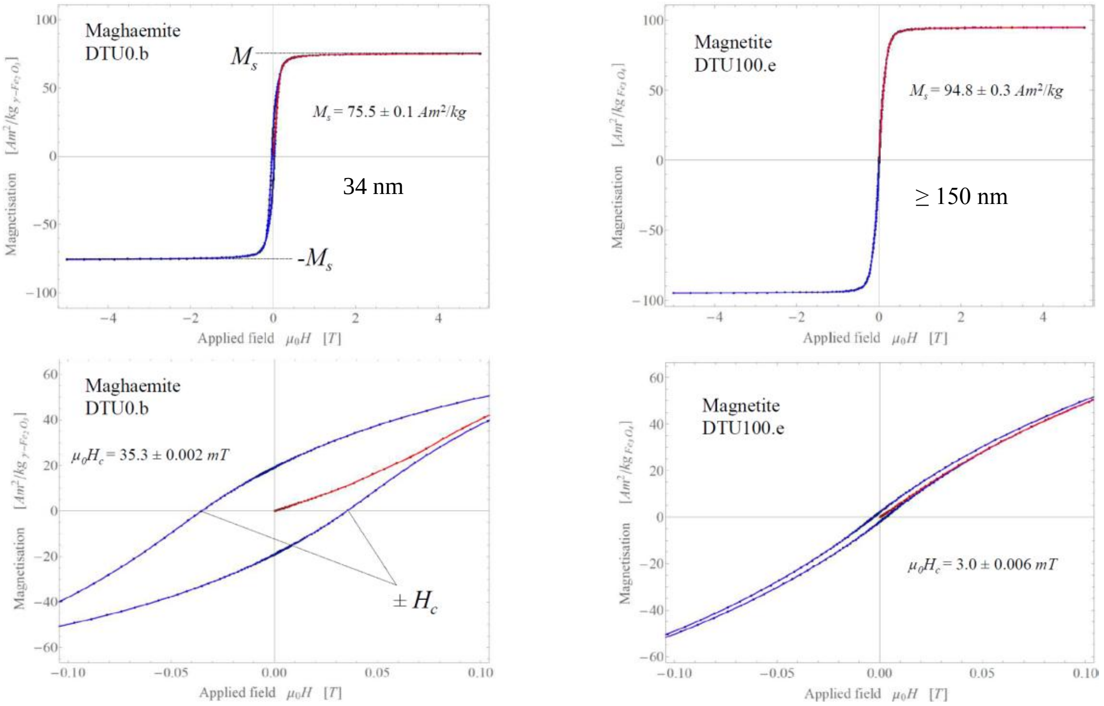

Fig. 1. Magnetic hysteresis measurement of a maghaemite sub-sample (left side) and a magnetite sub-sample (right side). Both lower diagrams are a zoom into the low-field region of the upper diagrams. The measurement cycle starts by increasing the applied field stepwise from 0 to +5 T (red curve). The field is then stepwise decreased from +5 T to -5 T and again increased to +5T (blue curves). At each field step, five individual measurement were recorded. The black points are average measurement values. Both samples differ significantly in grain size, which is reflected by Hc.

of the coercive force, is not affected by the mass and is much smaller, i.e., 0.01 and 0.3% for the maghaemite and the magnetite sample, respectively. Regarding accuracy, the average values obtained differ between 3 and 5% from the reference values published in the scientific literature (e.g., Fock *et al.* 2017), for H_c and M_s respectively; for both samples. Concluding can be said so far that the mass determination of the individual subsamples, which is in the order of a few milligrams, is the largest source of uncertainty.

Keywords: DC-magnetometry, uncertainty budget, magnetic hysteresis, magnetic nanoparticles.

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