3-2016

# A comparison of methods for the determination of the magnetocrystalline anisotrophy constant in an Fe3O4-based ferrofluid

Ronald Tackett
*Kettering University*

Megan Allyn
*Kettering University*

Vijayendra K. Garg
*University of Brasília*

Ehab H. A. Abdelhamid
*Wayne State University*

Prem Vaishnava
*Kettering University*

# A comparison of methods for the determination of the magnetocrystalline anisotropy constant in an $Fe_3O_4$-based ferrofluid.

**R.J. Tackett[1]**, M.M. Allyn[2], V.K. Garg[3], A.C. de Oliveira[3], E.A. Elhamid[4] and P.P. Vaishnava[1]

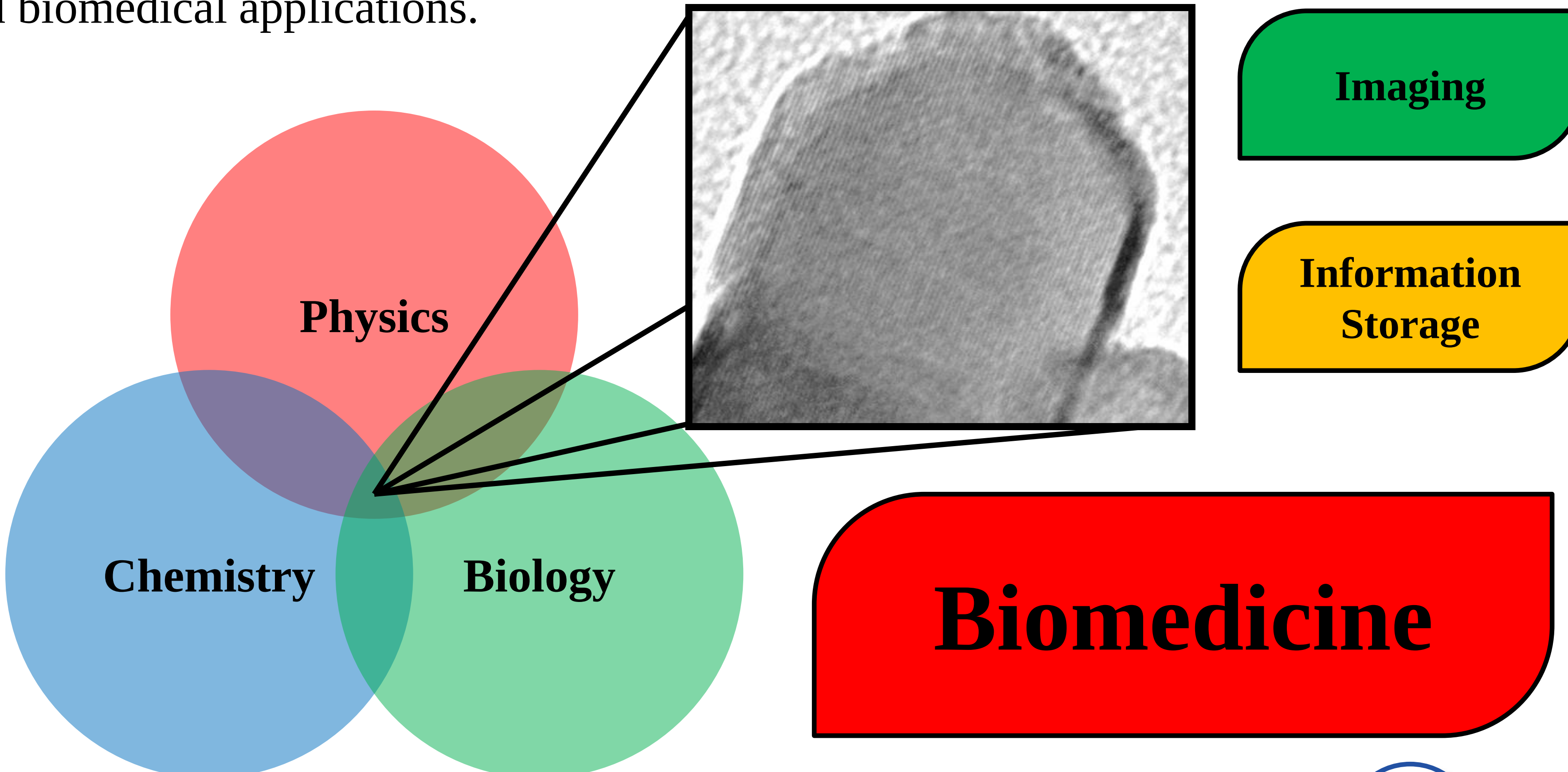
[1]Department of Physics, Kettering University, Flint, MI 48504

[2]Department of Chemical Engineering, Kettering University, Flint, MI 48504

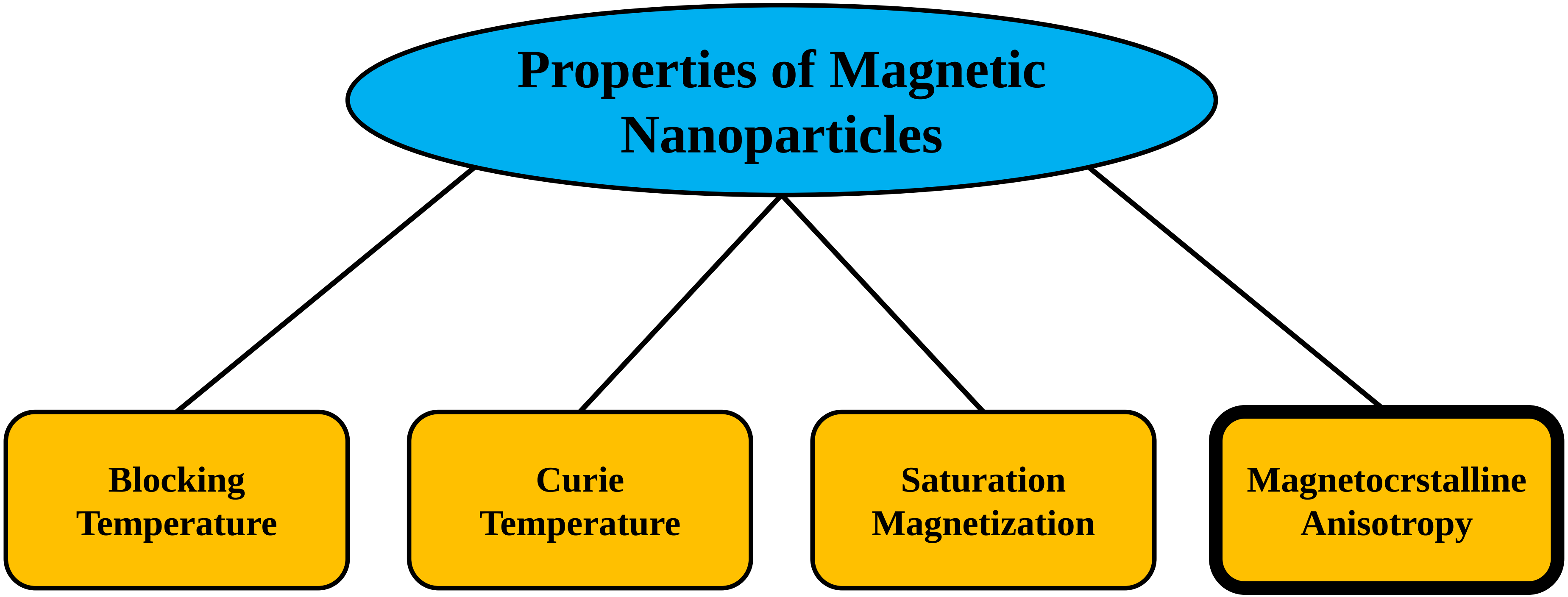
[3]Institute of Physics, University of Brasilia, Brazil 70910-900

[4]Department of Physics Wayne State University, Detroit, MI 48201

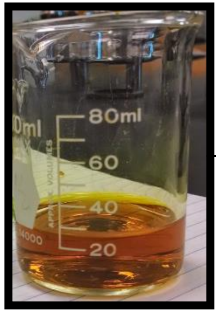
Nano-sized magnetic materials display physical and chemical properties which may be quite different from those of their bulk counterparts and have important technological and biomedical applications.



In order to compare the performance of these magnetic nanoparticles, their magnetic properties such as saturation magnetization, magnetocrystalline anisotropy, blocking temperature, and Curie temperature need to be studied in detail.



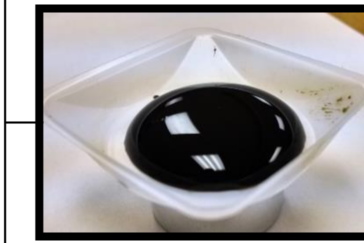
Iron-oxide ($Fe_3O_4$) nanoparticles were synthesized using a co-precipitation technique and coated with dextran in order to prevent agglomeration and to allow suspension in water.



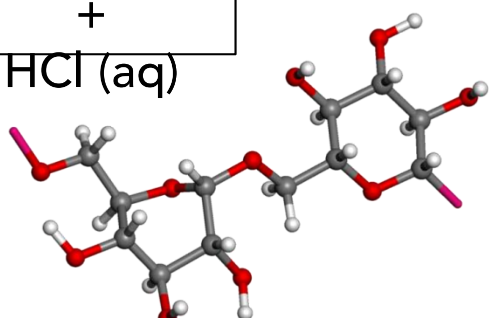
$FeCl_3 \cdot 6H_2O$ + HCl (aq)

$FeCl_2 \cdot 4H_2O$ + HCl (aq)

Add $NH_4OH$ (under $N_2$) until pH 10



Decant and Rinse MNPs



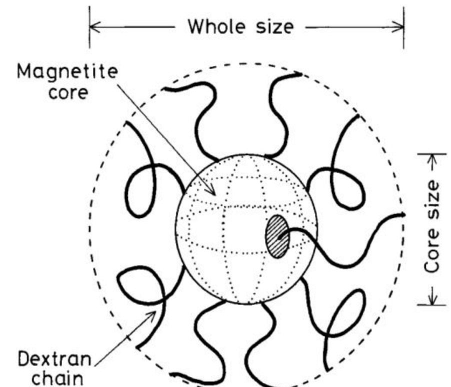
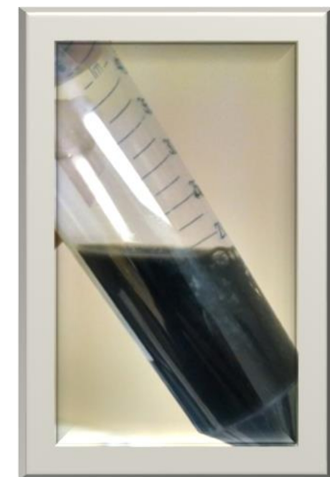
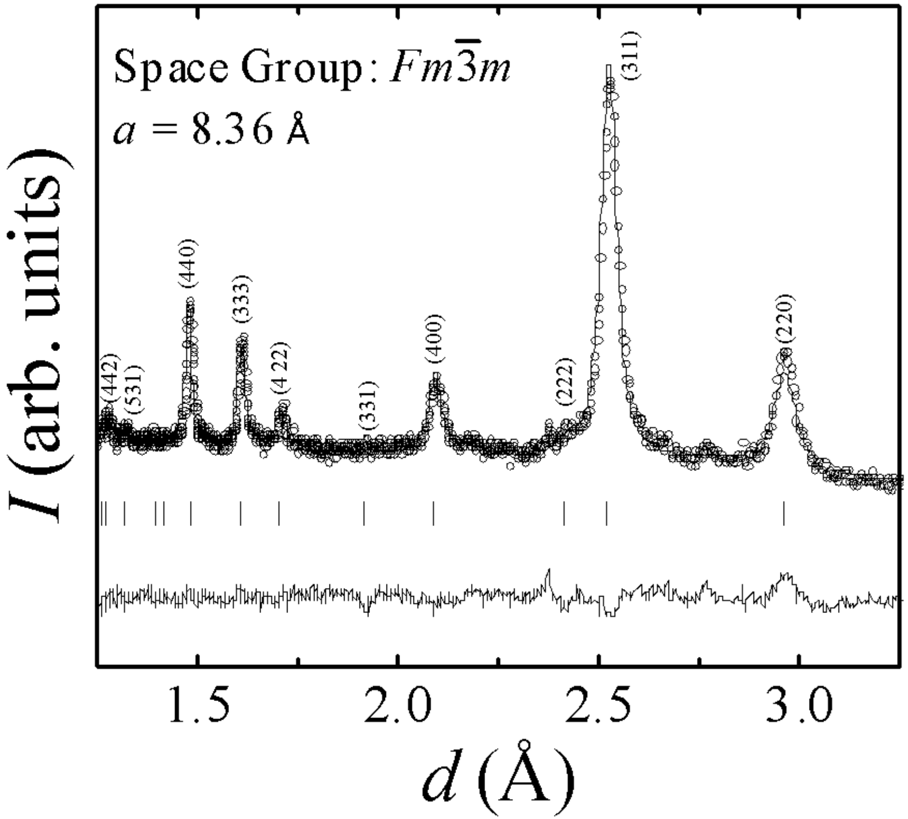


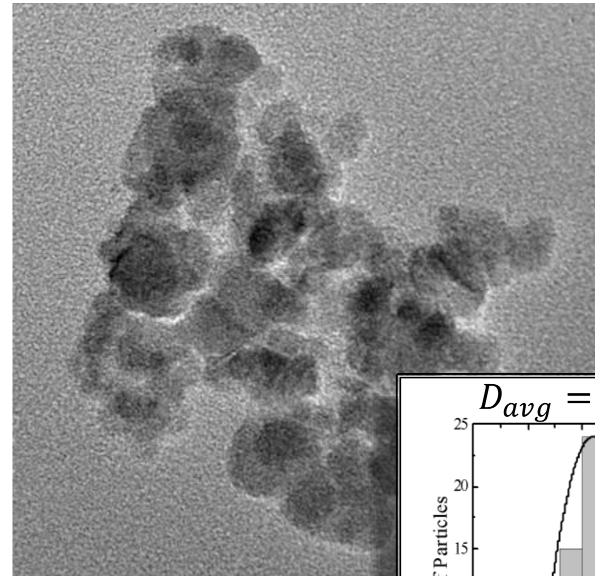

*Figure 1* Illustration of a DM complex in water. The size of magnetite core is exaggerated. The hatched area represents the area of core surface occupied by a dextran chain.

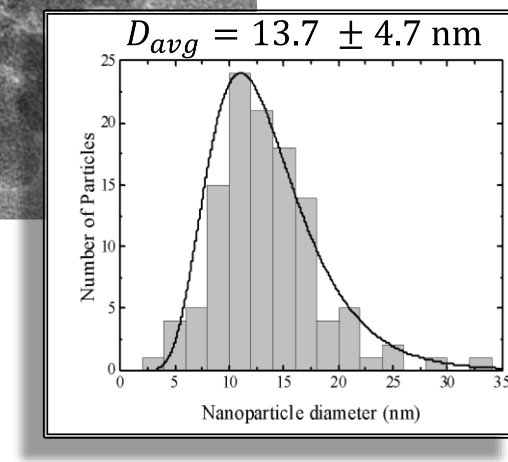
Xu et al. (2005) App. Surface Sci. 252, 494-500



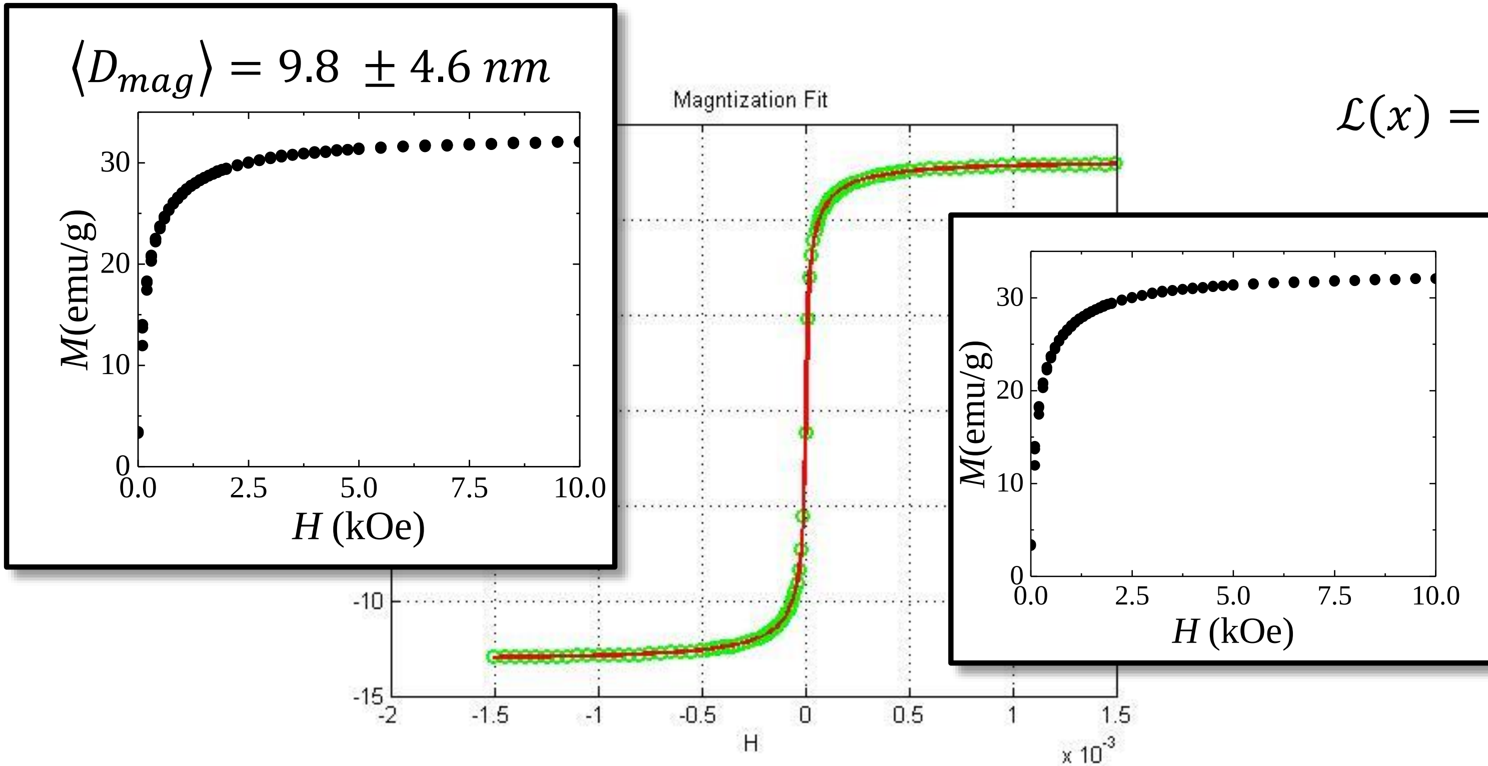
Powder x-ray diffraction and transmission electron microscopy were used to characterize the samples.





A fit of the room temperature $M(H)$ data to a Langevin function was used in order to determine the magnetic size of the nanoparticles.




$$\mathcal{L}(x) = \coth(x) - \frac{1}{x}$$

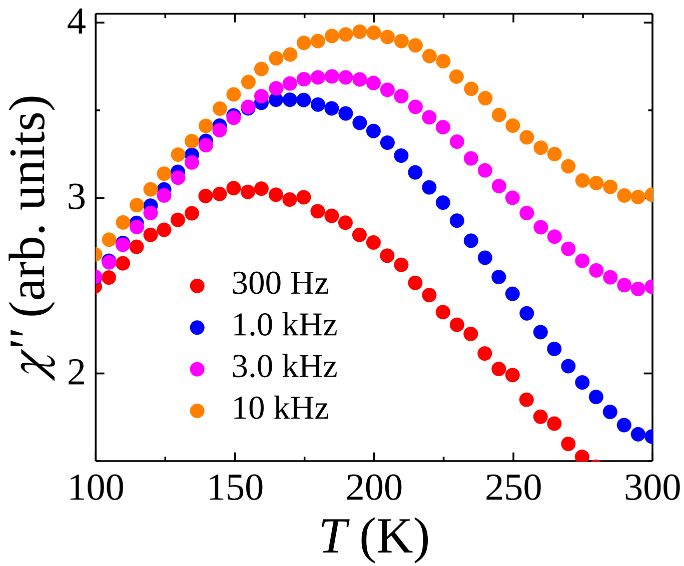
$$x = \frac{M_s V H}{k_B T}$$

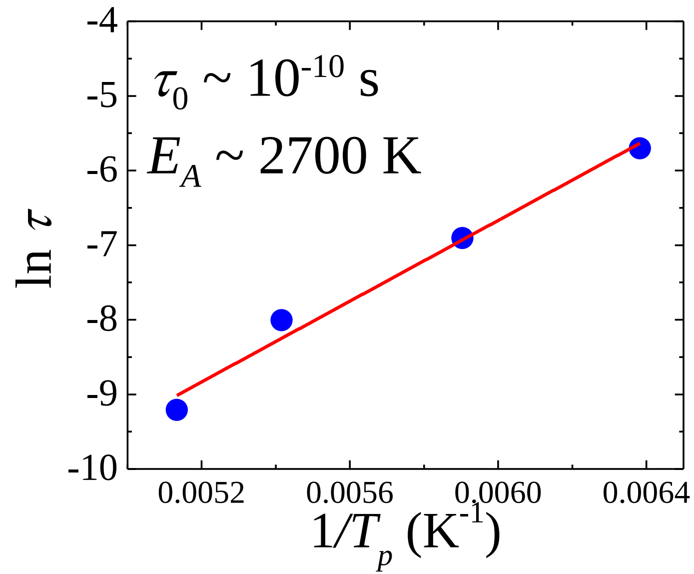
$$M(H) = M_s \frac{\int_0^\infty f(d) V \mathcal{L}(x) dD}{\int_0^\infty f(d) V dD}$$

$$f(D) = \frac{1}{\sqrt{2\pi}\sigma D} \exp\left\{-\frac{\left(\ln(D/D_0)\right)^2}{2\sigma^2}\right\}$$

Using the frequency dependence of the blocking temperature as measured using the ac magnetic susceptibility allows us to calculate the magnetocrystalline anisotropy constant.

$$K = 54.4 \pm 15.3 \text{ kJ/m}^3$$



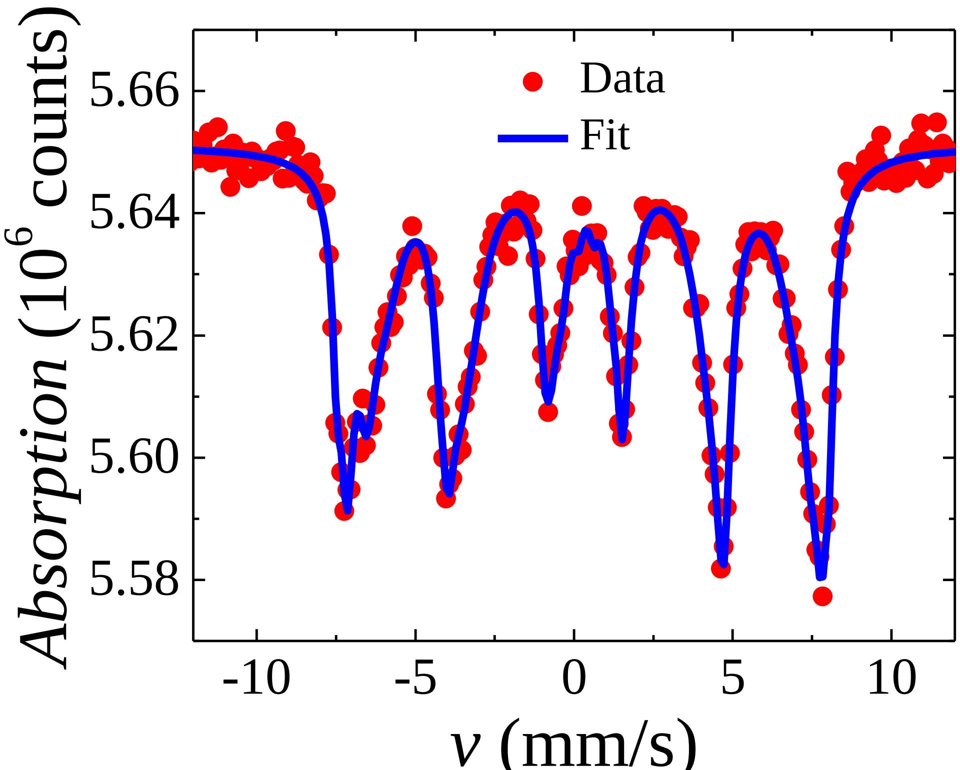




$$\tau = \tau_0 \exp\left\{-\frac{KV}{k_B T}\right\}$$

$$E_A = KV$$

Using the room temperature hyperfine field and the zero Kelvin hyperfine field determined via Mössbauer spectroscopy allows us to calculate the magnetocrystalline anisotropy constant.

$$K = 55.7 \pm 45.6\ \mathrm{kJ/m^3}$$




$$(B_{HF})_{RT} = 480\ \mathrm{kOe}$$

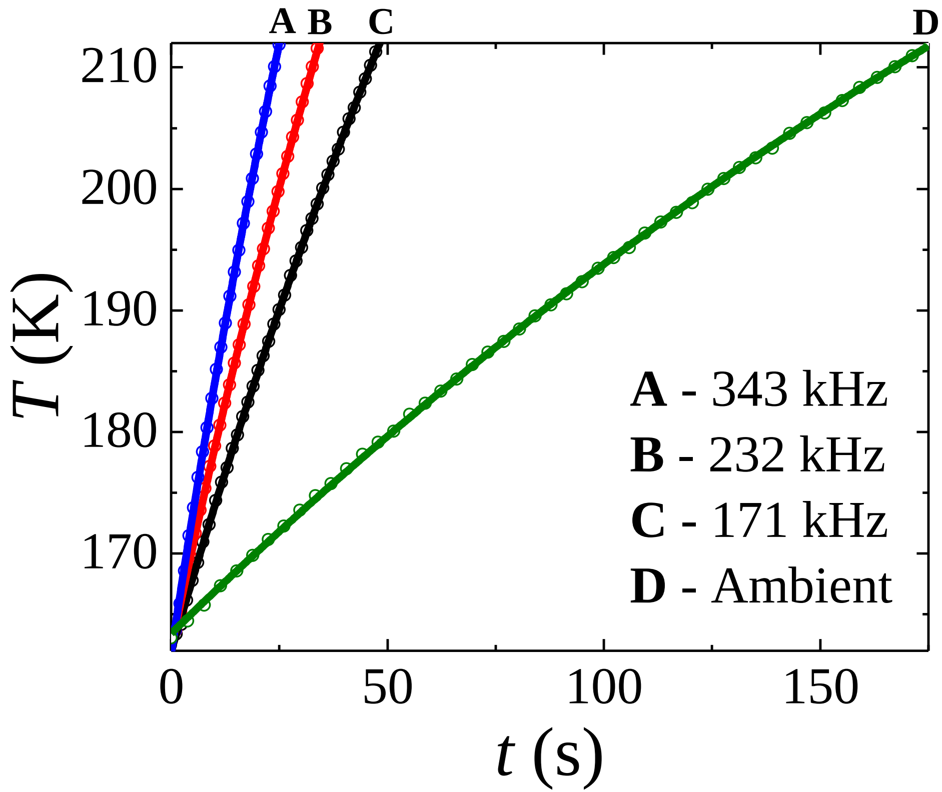
$$\frac{(B_{HF})_{RT}}{(B_{HF})_{0\mathrm{K}}} = (1 - kBT/2KV)$$

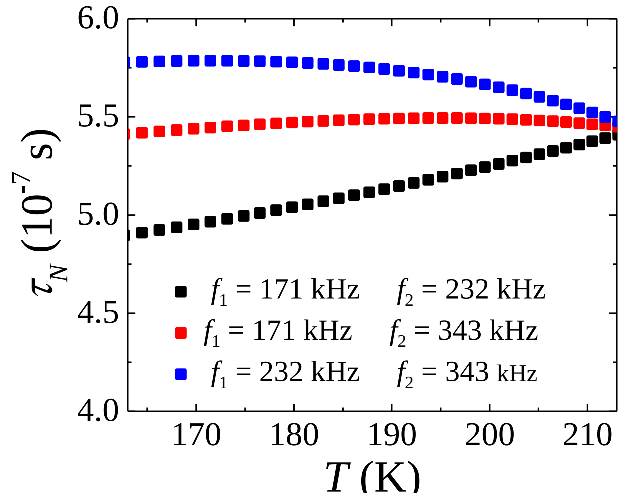
$$(B_{HF})_{0\mathrm{K}} = 517\ \mathrm{kOe}$$

Using the room temperature hyperfine field and the zero Kelvin hyperfine field determined via Mössbauer spectroscopy allows us to calculate the magnetocrystalline anisotropy constant.

$$K = 40 \pm 28 \text{ kJ/m}^3$$

$$\tau = \tau_0 \exp\left\{-\frac{E_A}{k_B T}\right\}$$




$$\tau_N = \frac{1}{2\pi f_1 f_2}\sqrt{\frac{f_1^2 - \alpha f_2^2}{(\alpha - 1)}}$$

$$\alpha = \frac{SAR_{f_1}}{SAR_{f_2}} == \frac{\left[\frac{\Delta T_{magnetic}}{\Delta t} - \frac{\Delta T_{ambient}}{\Delta t}\right]_{f_1}}{\left[\frac{\Delta T_{magnetic}}{\Delta t} - \frac{\Delta T_{ambient}}{\Delta t}\right]_{f_2}}$$

Finally, we compare the magnetocrystalline anisotropy constants as determined from three different experimental methods.

| Method | $K$ (kJ/m$^3$) |
|---|---|
| AC Magnetic Susceptibility | $18.7 \pm 15.3$ |
| Mössbauer Spectroscopy | $55.7 \pm 45.6$ |
| Hyperthermia Measurements | $40 \pm 28$ |


QUESTIONS?
COMMENTS?
CONCERNS?