Identification of the Curie Temperature Distribution from Temperature Dependent Magnetisation Data

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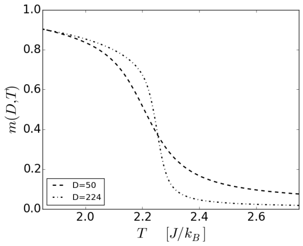
Introduction

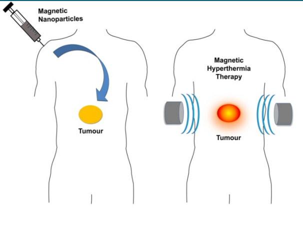
In HAMR[1]:

- T_C distribution affects the noise performance.



In Magnetic Hyperthermia[2]:

- Low T_C reduces tissue damage.



Ângela Andrade, Roberta Ferreira, José Fabris and Rosana Domingues (2011). Coating Nanomagnetic Particles for Biomedical Applications

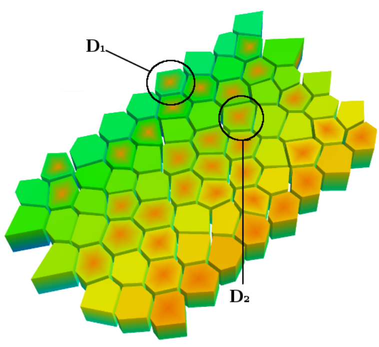
[1] Dieter Weller et al. "A HAMR Media Technology Roadmap to an Areal Density of 4 Tb/in". In: *IEEE transactions on magnetics* 50.1 (2014), p. 3100108

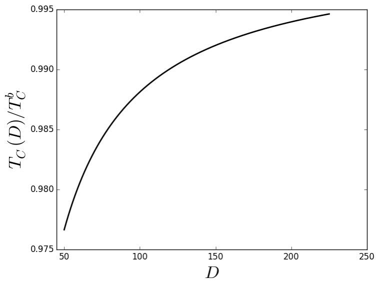
[2] I Apostolova and JM Wesselinowa. "Possible low-TC nanoparticles for use in magnetic hyperthermia treatments". In: *Solid State Communications* 149.25 (2009), pp. 986–990

Finite Sized T_C

Correlation length $\propto |T - T_C^b|^{-\nu}$

Grain size, $D \propto |T_C(D) - T_C^b|^{-\nu}$





$$f_D(D) \Longrightarrow f_{T_C}(T_C)$$

Previous Methods

2 Types:

- Explicit measurement of individual grains.[3]
- Implicit calculation using global measurements.[4]
  - Single measurement with magnetometer
  - Integral measure
  - Uses bulk relations

[3] Simone Pisana et al. "Curie temperature distribution in FePt granular media". In: *Magnetics, IEEE Transactions on* 51.4 (2015), pp. 1–5

[4] Andreas Berger et al. "Critical exponents of inhomogeneous ferromagnets". In: *Journal of applied physics* 91.10 (2002), pp. 8393–8395

Objectives

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- Develop a method to identify the T_C distribution which incorporates the finite size effects of the individual grains.
- Test this method against benchmark data in order to verify it's effectiveness for different distributions.

Our Method

Aggregate Magnetisation:

$$M(T) = M_0 \int_0^\infty D^d m(D,T) f_D(D) dD$$

Scaling Ansatz:

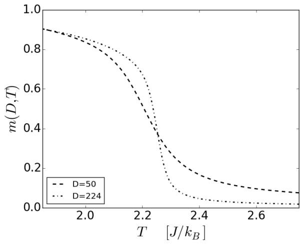
$$m(D,T) \propto D^{-\beta/\nu} \mu \left(D^{1/\nu} \frac{T - T_C^b}{T_C^b} \right)$$

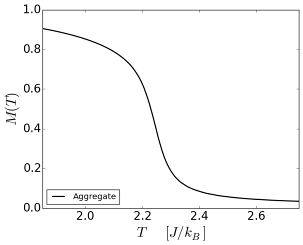
Change of Variables:

$$D = d_0 \left(\frac{t}{T_C^b} \right)^{-\nu} \qquad t \equiv T_C^b - T_C(D)$$

Final Result:

$$M(T) = M_0^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(d_0^{\frac{1}{\nu}} \frac{T - T_C^b}{t} \right) f_t(t) dt$$

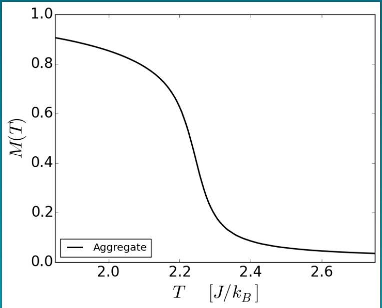


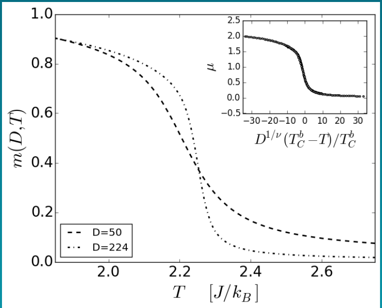


Finding f_t

$$M(T) = M_0^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(d_0^{\frac{1}{\nu}} \frac{T - T_C^b}{t} \right) f_t(t) dt$$

- $M(T)$: To be fitted
- d, ν, β, μ: Known information about the material
- d_0, T_C^b: May be known, otherwise taken from fit
- M_0^*, f_t [$\bar{t}$, σ_t]: Taken from the fit





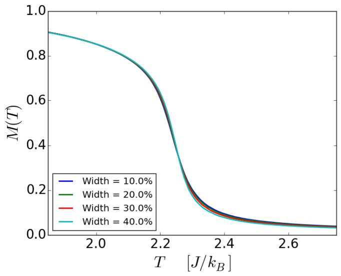
Test Case: 2D Ising Model

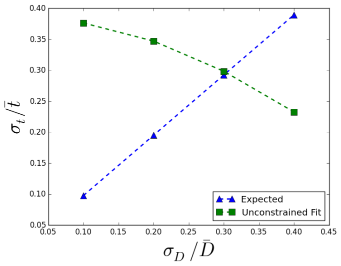
Used 2D Ising model as a benchmark:

- Easilly simulated
- Analytical results for β, ν, T_C^b...

Tested against different f_D:

- All mean $\bar{D} = 100$
- Standard deviation $\sigma_D = 10, 20, 30, 40$





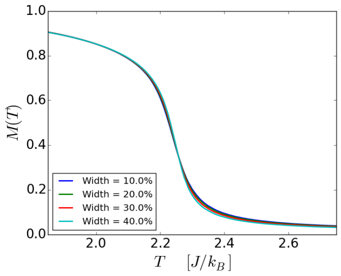
Test Case: 2D Ising Model

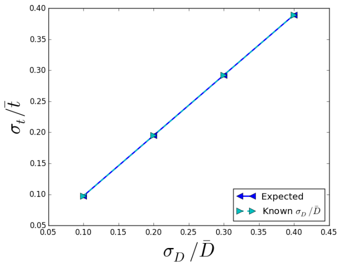
Introduce constraint from:

$$D = d_0 \left(\frac{t}{T_C^b} \right)^{-\nu}$$

$$\Rightarrow \sigma_t^2 = \bar{t}^2 \left(\left(1 + \frac{\sigma_D^2}{\bar{D}^2} \right)^{1/\nu^2} - 1 \right)$$

Works much better!





Conclusions

- Presented a universal method to find size dependent T_C distribution.
- Based upon fitting ensemble magnetisation:

$$M(T) = M_0^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(d_0^{\frac{1}{\nu}} \frac{T - T_C^b}{t} \right) f_t(t) dt$$

- Successfully tested against different size distributions f_D, given certain constraints.

Acknowledgements

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