Identification of the Curie Temperature Distribution from Temperature Dependent Magnetisation Data

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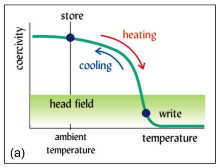
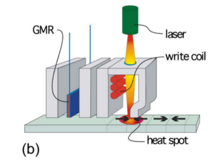
Introduction

In HAMR[1]:

- T_C distribution affects the noise performance

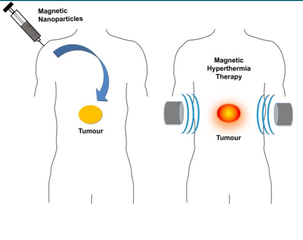




Elizabeth A Dobisz et al. "Patterned media: nanofabrication challenges of future disk drives". In: *Proceedings of the IEEE* 96.11 (2008), pp. 1836–1846

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

Defining Finite Sized T_C

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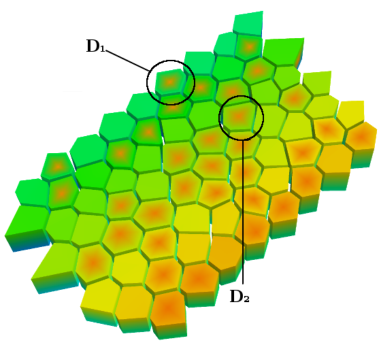
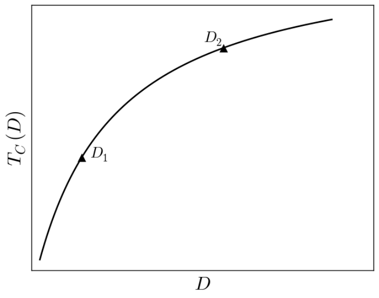
Correlation length $\propto |T - T_C^b|^{-\nu}$

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





Distribution in D leads to distribution in T_C

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

Currently Used Methods

- Explicit measurement of individual grains.[3]
  - Switching temperature is measured by a laser system set up
  - This is related to T_C
- Identification from macroscale measurements[4]
  - Single measurement with magnetometer
  - Integral measure
  - But 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 universal method to identify the T_C distribution which incorporates the finite size effects of the individual grains
- Test the method against a well quantified benchmark (2D Ising system) in order to verify it's effectiveness for different distributions.

Our Method

Magnetisation for Ensemble of Grains:

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

Single Grain Magnetisation:

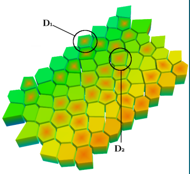
$$m(D,T) \propto D^{-\beta/\nu} \mu \left(D^{1/\nu} \frac{T - T_C^b}{T_C^b} \right)$$

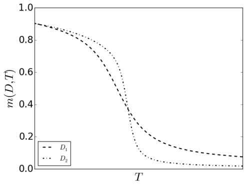
Change of Variables:

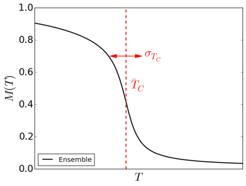
$$D = d_0 \left(\frac{T_C^b - T_C(D)}{T_C^b} \right)^{-\nu}$$

Final Result:

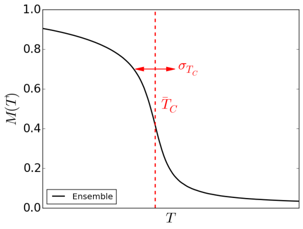
$$M(T) = M_0^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(\frac{T - T_C^b}{t} \right) f_t(t) dt$$

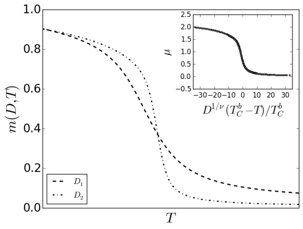






Finding f_t





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

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

$$\bar{T}_C = T_C^b - \bar{t} \qquad \sigma_{T_C} = \sigma_t$$

Test Case: 2D Ising Model

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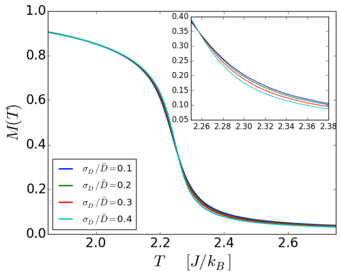
$$M(T) = M_0^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu\left(\frac{T - T_C^b}{t}\right) f_t(t) dt$$

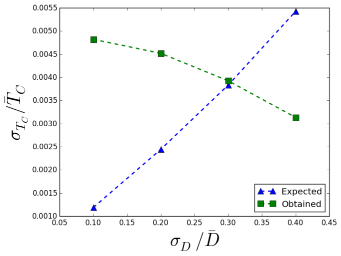
Used 2D Ising model as a benchmark:

- Simulated using Monte Carlo
- Analytical results for β, ν, T_C^b
  - $\beta = 1.25$
  - $\nu = 1$
  - $T_C^b \approx 2.269$

Tested against different f_D:

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





Test Case: 2D Ising Model

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Introduce constraint[5]:

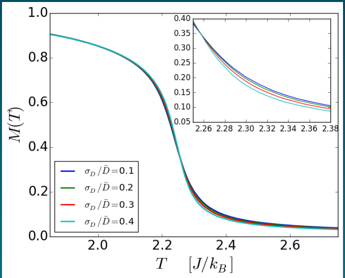
$$\Rightarrow \sigma_{T_C}^2 = (T_C^b - \bar{T}_C)^2 \left(\left(1 + \frac{\sigma_D^2}{\bar{D}^2} \right)^{1/\nu^2} - 1 \right)$$

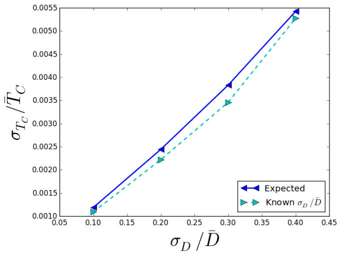
In the Ising model:

$$\nu = 1$$

$$\Rightarrow \sigma_{T_C} = (T_C^b - \bar{T}_C)\frac{\sigma_D}{\bar{D}}$$

Fitted results far better!





[5] O Hovorka et al. "The Curie temperature distribution of FePt granular magnetic recording media". In: *Applied Physics Letters* 101.5 (2012), p. 052406

Conclusions

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

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

- Successfully tested against different size distributions f_D from the 2D Ising model (without a loss in generality).
- The nature of the benchmark data meant a narrow f_{T_C} and strong parameter correlation.
- An additional constraint was introduced to combat this:

$$\sigma_{T_C}^2 = (T_C^b - \bar{T}_C)^2 \left(\left(1 + \frac{\sigma_D^2}{\bar{D}^2}\right)^{1/\nu^2} - 1\right)$$

- This issue may not be as significant in other systems. e.g. Heisenburg model, FePt Hamiltonian e.c.t.

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