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Impact of nanoparticle easy-axis reorientation on heating efficiency in magnetic hyperthermia

Author: Iago López Vázquez[1]

Co-authors: David Serantes Abalo[1]; Kazuya Okada[2]; Roy Chantrell[3]; Siraj Ul Haq[1]; Òscar Iglesias[4]

[1] *University of Santiago de Compostela, A Coruña, Galicia, Spain*
[2] *Saitama Institute of Technology*
[3] *School of Physics, Univ. of York, UK*
[4] *Dept. de Física de la Matèria Condensada and IN2UB, Universitat de Barcelona, Spain*

Magnetic hyperthermia efficiency is governed by the interplay between internal magnetization dynamics and the rotational response of nanoparticles in viscous media. Here we investigate how easy-axis reorientation under AC magnetic fields influences hysteresis losses in an assembly of non-interacting uniaxial magnetic nanoparticles [1,2]. Using a coupled Landau-Lifshitz-Gilbert and Brownian dynamics approach [3], we analyse the stationary orientation reached by the anisotropy axis and its dependence on particle size, excitation frequency and medium viscosity. As shown in Fig. 1, the system exhibits a transition from predominantly perpendicular easy-axis configurations at low field amplitudes to parallel/antiparallel alignment at higher fields. This transition is strongly controlled by particle size and frequency: increasing either parameter shifts the crossover towards larger field amplitudes. By contrast, viscosity mainly affects the transient evolution and the amplitude of the residual oscillations around the stationary state, while having a much weaker influence on the final orientational regime. We then relate this orientational behaviour to the microscopic reversal dynamics by distinguishing between switching and non-switching cycles. Switching trajectories, associated with reversal between anisotropy minima, exhibit significantly larger hysteresis-loop areas than non-switching trajectories and therefore dominate heat dissipation. The onset of switching closely follows the orientational crossover, revealing a direct connection between easy-axis alignment and heating performance. Overall, our results show that the main impact of viscosity at the single-particle level is kinetic rather than stationary, whereas size and frequency determine the orientational state that enables efficient switching-driven losses.

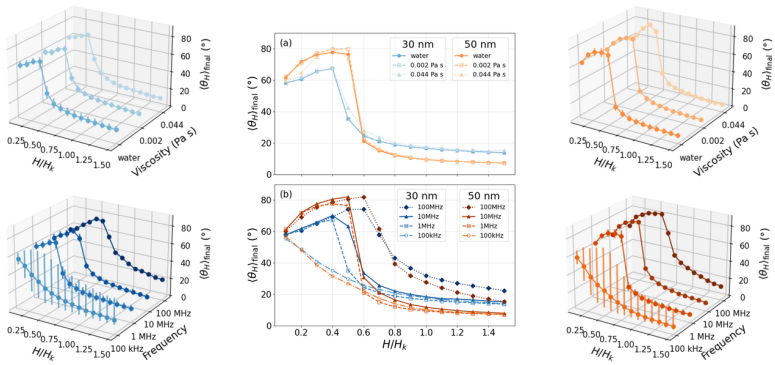

Figure 1: Final average easy-axis orientation as a function of reduced field amplitude, showing the transition from perpendicular to parallel/antiparallel alignment.

[1] D. B. Reeves and J. B. Weaver, *Applied Physics Letters* 104, 102403 (2014).
[2] H. Mamiya and B. Jeyadevan, *Scientific Reports* 1, 157 (2011).
[3] K. Okada and A. Satoh, *Journal of Magnetism and Magnetic Materials*, 173259 (2025).

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