

Surface-Chemistry–Controlled Magnetic Heating of Iron Oxide Nanoparticles and Nanospheres under High-Frequency Alternating and Rotating Magnetic Fields

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Magnetic heating of iron oxide nanomaterials is governed by the interplay between intrinsic magnetic relaxation and mechanically enabled dissipation pathways, both of which are strongly affected by surface chemistry and environmental confinement.

Here, we investigate the heating behavior of iron oxide nanoparticles and larger nanospheres under alternating magnetic fields (AMF) and high-frequency rotating magnetic fields (RMF) in liquid dispersions and mechanically restricted hydrogel matrices. Iron oxide nanoparticles in the superparamagnetic size regime (8–12 nm) are considered alongside larger nanospheres to elucidate the role of particle size, collective effects, and mechanical constraints on magnetic dissipation. Bare and polymer-functionalized iron oxide nanomaterials coated with poly(caffeic acid) (PCA), poly(syringic acid) (PSA), polydopamine (PDA), and polynorepinephrine (PNE) are used to systematically tune interparticle interactions and surface adhesion. The specific absorption rate (SAR) is measured calorimetrically as a function of magnetic field amplitude H and frequency f , allowing direct comparison between excitation modes and environments. Mechanical confinement in hydrogels suppresses rotational losses and shifts heating efficiency toward Néel-dominated regimes, revealing pronounced surface-chemistry-dependent changes in optimal excitation conditions. Nanospheres exhibit enhanced sensitivity to excitation mode and confinement compared to conventional nanoparticles, consistent with an increased contribution of collective or internally driven loss mechanisms. The ratio $\text{SAR}_{\text{RMF}}/\text{SAR}_{\text{AMF}}$ is introduced as a practical metric for identifying dissipation pathways that remain efficient under restricted motion. These results provide a physically grounded strategy for maximizing heating efficiency per unit mass while limiting material load, offering realistic design rules for magnetic hyperthermia in soft and biologically relevant environments.

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