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Hard meets soft: tuning binary ferrofluids

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Binary ferrofluids composed of multicore nanoflowers of magnetically hard $CoFe_2O_4$ and magnetically soft $MnFe_2O_4$ are studied as a way to optimise heat dissipation while suppressing aggregation – properties essential for biomedical applications. Bulk magnetometry and molecular dynamics simulations were combined to elucidate their behaviour [1]. Experiments show wasp-waisted hysteresis, composition-dependent coercivity, and strong protocol dependence (field cooling). Simulations reproduce these trends and reveal the underlying structure-property coupling:
(i) under field, $CoFe_2O_4$ forms chains that dominate collective switching;
(ii) adding $MnFe_2O_4$ "poisons" these chains – shortening and de-branching clusters – thereby lowering coercivity and loop area relative to a weighted superposition of the individual component responses without interactions;
(iii) dipolar coupling reciprocally hardens the magnetically soft phase and softens the magnetically hard phase even without large-scale aggregation;
(iv) at higher total volume fraction (φ = 0.1) magnetically soft particles still suppress chain growth, reducing mean cluster size by up to an order of magnitude while keeping heating-relevant hysteresis close to Stoner-Wohlfarth expectations.

These results establish composition-controlled microstructure as a means to decouple thermal output from aggregation: $CoFe_2O_4$:$MnFe_2O_4$ mixtures can be tuned to enhance loss mechanisms while mitigating aggregation, offering a route to binary ferrofluids optimized for magnetic hyperthermia and drug delivery.

References

[1] M. Khelfallah et al. *Nanoscale.* 2026. doi:10.1039/D5NR05218A.

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