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Interparticle interactions between superparamagnetic nanoparticles: The modified mean-field approach

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A modified mean-field model (MMFM) is introduced which takes account of the magnetic interparticle interactions between superparamagnetic nanoparticles (SNPs). The MMFM was first developed for liquid suspensions of ferromagnetic particles (ferrofluids) [1]. In this work, the MMFM is extended to include fluctuations of the moments within SNPs that are either suspended in a carrier liquid or immobilized in a solid matrix. The MMFM is based on there being two magnetic fields acting on a given SNP: the external magnetic field; and the magnetic field created by all other SNPs assuming no orientational correlations.

The MMFM describes accurately the static magnetic properties of moderately concentrated ferrofluids with interaction strengths comparable to the thermal energy [2,3], and it even works when the interactions are strong enough to stabilize chain-like aggregates. The MMFM predicts that the presence of superparamagnetic (internal) degrees of freedom does not affect the static magnetic properties, and in all cases the interactions lead to a significant enhancement of the initial static susceptibility [4].

When SNPs are immobilized in solid matrices –as in ferrocomposites –the loss of translational and rotational degrees of freedom leads to different properties [5]. The MMFM yields simple expressions that depend on the distribution of the orientations of the SNP easy axes with respect to the external field. Interactions are most important in the case of parallel texturing in which the easy axes are aligned with the external field. In this case, the initial static susceptibility can be several times larger than that of non-interacting particles.

The physical transparency of the MMFM means that it can also be applied to the dynamic magnetic response, as has been done for ferrofluids [3,6]. The results are simple corrections to the Debye expression for the frequency spectrum of the dynamic susceptibility of non-interacting particles. The most significant change to the spectrum is a shift in the maximum of the imaginary part to lower frequency, signaling an increase in the characteristic magnetic relaxation time. This arises from collective dynamics of the SNPs caused by the magnetic interparticle interactions.

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References

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