Relaxation responses of magnetic nanoparticles immobilized by hydrocolloid polymer (agar)

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Upon current research-trend in magnetic theranostics (*e.g.*, magnetic hyperthermia, magnetic particle imaging), the interparticle dipolar-magnetism in an interacting magnetic-nanoparticle system principally highlights a significant difference of magnetic properties observed. For a fluidic environment, to confirm how this magnetic interaction changes, is practically easy through controlling the particle concentration, in which such a dense ferrofluid may be associable with a close mean-interparticle-distance of the suspended particles. However, for a solid-phase medium in which magnetic nanoparticles are supposed to be physically immobilized, it is more difficult as particle packing-density may vary upon sample volume. To this concern, such adjusting the shell-thickness of silica-coated magnetic nanoparticles[1)] may become an option to study the corresponding magnetic properties from a simple powder-sample, but we preferably offered the use of hydrocolloid polymer (*i.e.*, agar) to solidify the initial liquid-sample while attempting to maintain its volume. Agar is a polysaccharide complex which can form a thermo-reversible gel due to the molecular interaction of 3D helix structural framework holding the water molecules within the respective interstices. Therefore, this work was aimed to identify the relaxation behavior of the agar-solidified ferrofluids owing to the density of agar.
Experimentally, we solidified the sodium olefin sulfonate-coated magnetite-nanoparticle suspensions (*i.e.*, M300 ferrofluid purchased from Sigma-Hi Chemical) having the particle concentration adjusted to 27 mg-Fe ml^{-1}, by varying the mass of agar powder for 0.1 ml sample-volume. The measurements of complex magnetic susceptibility, then, were performed via a phase-sensitive detection (*i.e.*, lock-in amplifier) for 100 Hz to 100 kHz at 50 Oe field-amplitude. As illustrated in Fig. 1(a), adding agar to the ferrofluid sample may restrain the random Brownian motions of the suspended particles, after gelation process finishes. Fig. 1(b) further confirms that a sufficiently high agar concentration leads to a perfect particle immobilization, in which the Brownian relaxation responses diminish. We indicated a spectral shift of relaxation response suggesting the existence of the oscillatory-field induced particle rotation for an increasing agar concentration. We believe that the underlying mechanism was not the morphological change of hydrodynamic volume, but it might be related to the viscosity change of the micro-space on which the particles occupied.

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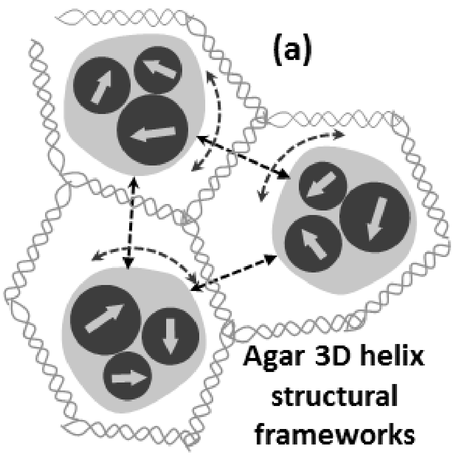
Reference

1) Nicolás Pérez *et al*, J. Appl. Phys., **121** (2017) 044304.



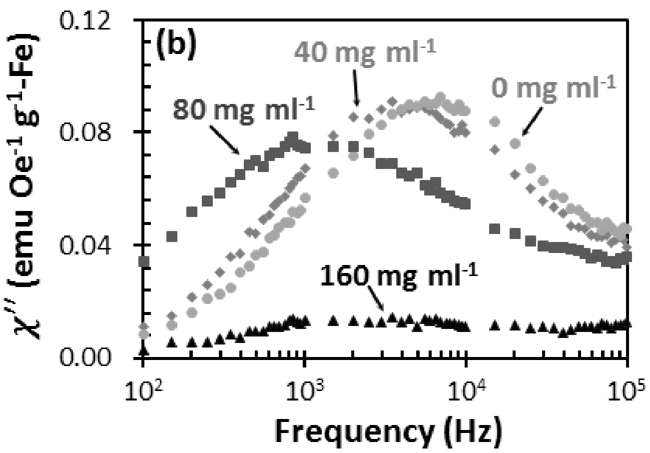


Fig 1. Interstitial 3D helix structures during gelation process allows magnetic particles to be physically trapped (a), however imaginary part of magnetic susceptibility reveals the possibility of particle rotation, depending of agar concentration (b).