Out-of-equilibrium dynamics of a frozen ferrofluid

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Ferrofluids are examples of complex fluids composed of magnetic nanoparticles dispersed in a liquid, which are well known for their use in numerous technological applications [1]. While their physical properties are now well understood, at least in the case of dilute systems, they can change drastically for increasing concentrations yielding for example to a colloidal glass transition at room temperature [2]. In the work reported here are more interested in the low temperature magnetic behavior of concentrated ferrofluids. Indeed, there has been very much interest recently in such frozen ferrofluids as they can be regarded as systems analogous to spin glasses in which the randomly located nanoparticles bearing giant magnetic moments act as superspins interacting via random long range dipolar interactions. Previous investigations have found that such systems can exhibit features similar to that of spin glasses such as non trivial aging and memory effects at low temperature [3].

In this presentation we report a study of the low temperature out-of-equilibrium magnetic properties of a concentrated dispersion (volume fraction $\Phi =$ 35 %) of γ-Fe_2O_3 nanoparticles with a mean diameter of 8.5 nm dispersed in H_2O. The magnetic measurements were performed with a commercial SQUID magnetometer in the range $5-300$ K. The magnetic Field Cooled (FC) and Zero Field Cooled (ZFC) dc susceptibilities, χ_{FC} and χ_{ZFC}, show a high temperature behavior in $1/T$ and the appearance of irreversibilities below a freezing temperature $T_g = 100$ K: χ_{FC} becomes T-independent while χ_{ZFC} displays a cusp at T_g. Complementary ac susceptibility measurements at various frequencies indicate clearly the critical nature of this transition towards a glassy superspin glass state.

The out-of-equilibrium dynamics of this frozen ferrofluid below T_g was probed by Thermo Remanent Magnetization (TRM) relaxation experiments. The sample was quenched from an initial temperature T_0 well above T_g down to a working temperature $T_m = 0.7$ T_g, in a small magnetic field of 0.5 Oe, and kept at this temperature for a waiting time t_w. The field was then cut off and the decay of the TRM was recorded as a function of time t. In the results, the aging nature of the dynamics is evidenced as a t_w dependence of the TRM decay: the longer the time spent below T_g the slower the response to the field cut-off. To compare this superspinglass sample with atomic spin glasses, we try to use the scaling laws which apply to TRM in spin glass to describe our data. Fig. 1 shows a scaling plot of several TRM relaxations curves (normalized by the FC magnetization and corrected from a stationary part) obtained for different t_w. All the curves fall on a unique master curve when plotted as a function of a reduced time variable λ/t_w^μ which at first order is equivalent to t/t_w and shows that the characteristic relaxation time of a system of age t_w is of order t_w itself.

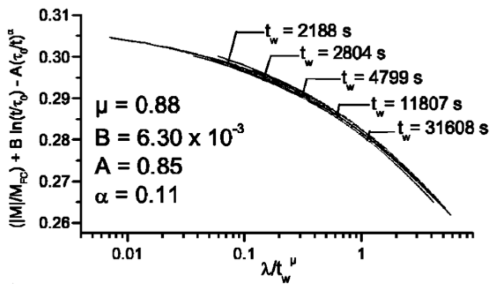

Figure 1: Scaling plot of TRM relaxations recorded at 0.7 T_g with a field of 0.5 Oe in a frozen water-based maghemite ferrofluid (volume fraction $\Phi = 35$ %, $T_g = 100$ K).

Further investigations of the out-of-equilibrium dynamics of this frozen ferrofluid sample, including its sensitivity to temperature perturbations, were done using ac susceptibility measurements and reveal other interesting features, such as memory effects similar to the ones observed in atomic spin glasses.

References

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