FERROFLUID DYNAMICS: SPIN ECHO EXPERIMENT

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Macroscopic properties of ferrofluid (FF) are related with dynamics of nuclear and magnetic subsystems. The interaction between them causes specific phenomena known as selforganization [1] which treatment can be based on knowledge of FF dynamics. The aim of this experiment is the research of dynamic fluctuations of nuclear and spin density in FF by variation of dipole energy and external field. Magnetite dispersions in light and heavy water or tetradecane in concentration range $C = 0.55—5$ *vol.%* were used as the samples.

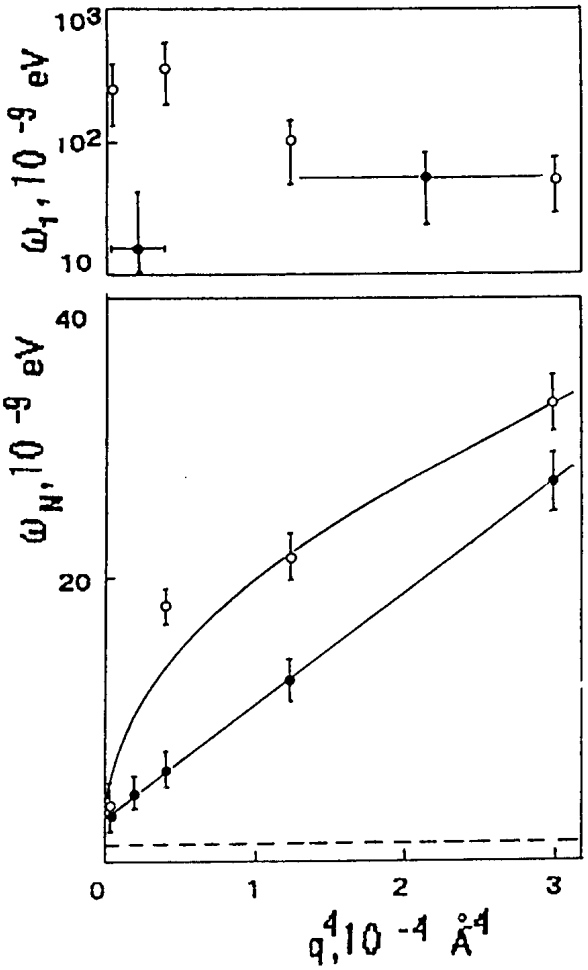

Fig. Magnetic (a) and nuclear (b) inelasticity versus momentum transfer. Zero field: full circles. Strong field H=700 *Oe*: open circles. Full curve is shown for normal diffusion with coefficient calculated using particle size from diffraction. Dashed line corresponds to rotational diffusion of particle

Particles were stabilized by double molecular layer of sodium salt of oleic acid (water FF) or by monomolecular layer of oleic acid (in tetradicane). Measurements were carried out on IN11 at ILL at room temperature with magnetic field $H = 0—1.5$ *kOe*. Size distribution of magnetic grains was analized using electron micrographs. This distribution has a log-normal form with standard deviation ~0.5 and the most probable value of particle radius R_p~30—50 Å. The most full study has been performed for deuterated FF with $C = 2.42\%$.

The scattering law observed for nuclear and both magnetic correlations (transversal and longitudinal to applied field) can be described by the function $\sigma_{N,1,2} = \sigma^0_{N,1,2} \cdot (1 + q^2 \cdot R^2_{N,1,2})^{-2}$ where each

$\sigma(q) = \int(d^2\sigma(q, \omega)/d\Omega\, d\omega)d\omega$ is integrated over energy transfer $\hbar\omega$ for a given momentum transfer $\hbar q$. In zero field ($\sigma_1 = \sigma_2$) the length of magnetic correlation is smaller than that of nuclear one, $R_1 \sim 15$ Å, and the ratio of the cross sections is also very small, $\sigma_1/\sigma_N \sim 0.04$.

The field $H = 700$ *Oe* causes the growth of longitudinal correlations and the cross section increases $\sigma_2/\sigma_M \sim 0.6$ with decreasing σ_1. There was no influence of applied field on nuclear correlations. An essential growth of correlation lengths $R_1 \leq R_N \leq R_2 \sim 17$ Å is not observed. These results indicate that there is no processes of particle aggregation in magnetic field. At the same time magnetization induces a strong change of nuclear and magnetic dynamics (fig.). The behaviour of nuclear subsystem without the field does not follow the simple translational diffusion and the soft relaxation mode with energy $\omega_N = \omega_0 = D_0 \cdot q^4$ has been observed. This anomaly can be explained assuming the existense of specific dynamic fractal (for instance a random walk chain of particles connected with dipole interactions). This bounds are broken in a strong field and normal diffusion dominates (fig.). Solid line shows the energy behaviour $\omega_{NF} = \omega_F + D_F \cdot q^2$ calculated with diffusion coefficient D_F using Stokes formula by substitution of hydrodynamic radius of particle from the difraction found. Comparison of diffusion coefficients in both cases yields the value of bound length $L = (D_F/D_0)^{1/2} \sim 200$ Å of an order of averaged distance between particles $d \sim 270$ Å.

Magnetic inelasticity in zero field demonstrates superparamagnetism of single domain particles according to Neel's treatment [2,3], i.e. thermal fluctuations of magnetization direction. Particle rotation is too slow and leads to inelasticity ~1 *n eV*. At low $q \leq 1/d$ the transversal spin relaxation depends on local magnetic field fluctuations $\delta H \sim m^3/d^6 kT$ whose contribution to total energy will be $\omega_1 \sim \gamma \cdot \delta H \sim 10$ *n eV* where γ is the ratio of magnetic momentum to angular momentum for electron, m is magnetic moment of particle and kT is energy of thermal fluctuations. Polarization of FF in high field initiates strong local fluctuations which provide high relaxation rate. The energy estimation is $\omega_{1F} \sim \gamma \cdot m/d^3 \sim 350$ *n eV*. This concept of random fields agrees with experimental q-dependence of energy. The increasing of field deviation with distance between particles being taken into account we obtain a scaling law for the energy $1/q$ for $q \geq 1/d$.

Thus the analysis of neutron scattering shows dynamic nature of FF ordering and allows to understand the magnetic and nuclear subsystem interaction by the FF magnetization.

References

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