Interaction effect in ferrofluids by small-angle neutron scattering

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Small-angle neutron scattering (SANS) is applied to different types of magnetite-containing ferrofluids to reveal a character of interparticle interaction in the absence of external magnetic field. The particle concentration dependence of the scattering was followed and analyzed in respect to deviations from the core-shell model of non-interacting particles. The complete mathematical treatment of this effect is quite complicated for ferrofluids, which are the systems of polydisperse particles interacting with orientation dependent potentials. Still, qualitatively the character of the interaction can be estimated [1,2] from the effective structure-factor, which is a ratio of the scattering curve comprising the interaction effect and the curve obtained at the smallest particle concentration corresponding to the non-interacting system. The examples of such analysis are presented in Figs.1,2. The neutron scattering consists of two (nuclear and magnetic) contributions providing information about nuclear and magnetic correlations in the system, respectively. For the studied single-layered ferrofluids on organic H-carriers the effect of magnetic neutron scattering is negligible, so the scattering curves in this case give only the effective nuclear structure-factor, $S_N(q)$, shown in the inset in Fig.1,*a*. Its character corresponds to an attractive potential with a short-range (sterical) repulsion at the particle interface. The effect of this structure-factor on the scattering is not strong, so that the model

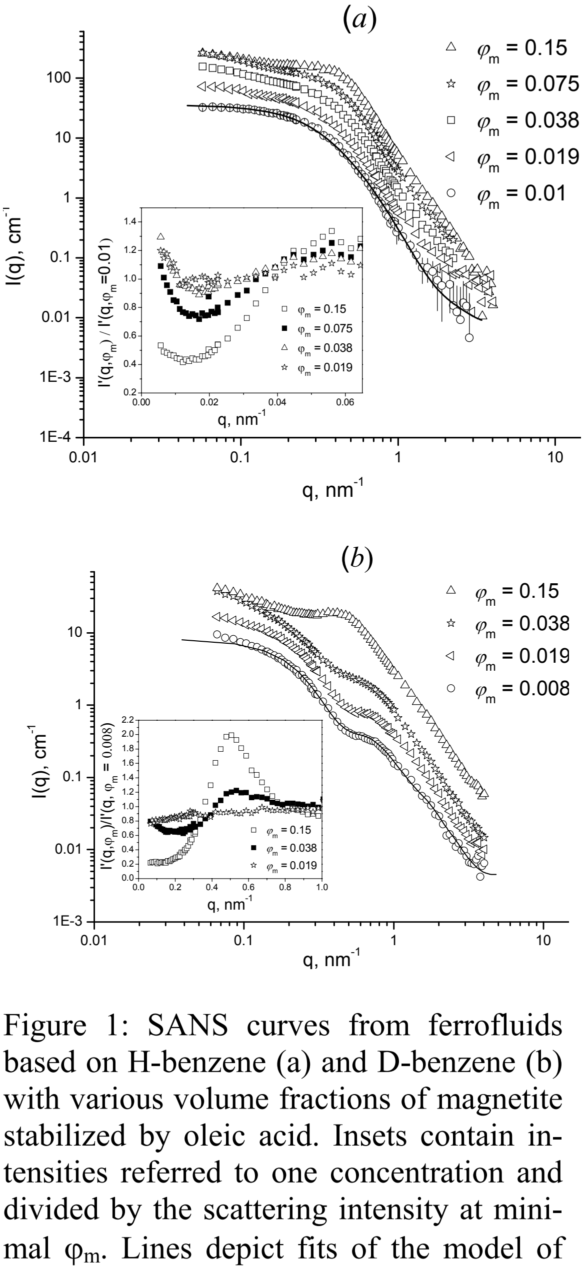

Figure 1: SANS curves from ferrofluids based on H-benzene (a) and D-benzene (b) with various volume fractions of magnetite stabilized by oleic acid. Insets contain intensities referred to one concentration and divided by the scattering intensity at minimal φ_m. Lines depict fits of the model of non-interacting core-shell particles at minimal values of φ_m.

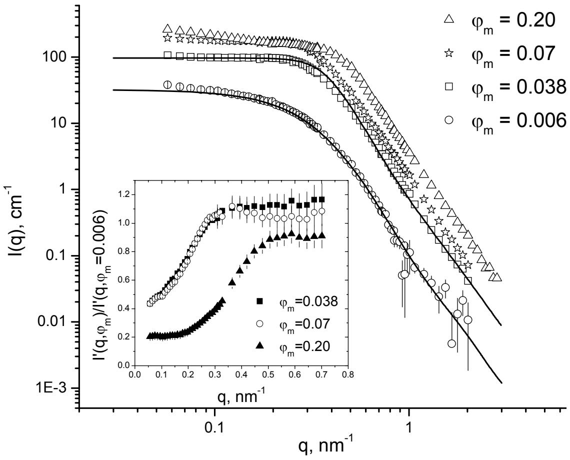

Figure 2: SANS curves from ferrofluid based on H-pentanol with various volume fractions of magnetite stabilized by double layer of oleic acid and DBS. Inset contains intensities referred to one concentration and divided by the scattering intensity at minimal φ_m. Lines depict fits of models of non-interacting core-shell particles (φ_m = 0.006) and core-shell particles with hard sphere interaction (φ_m = 0.038).

of non-interacting particles can be fitted well for the fluids with the magnetite volume fraction up to 5 % (~10 % of particle concentration including surfactant shell). For D-carriers the influence of magnetic scattering is significant, which changes the effective structure-factor in a complicated way:

$$S_N(q) \to \sim S_N(q)(1+\gamma(q)S_M(q)), \qquad (1)$$

where $S_M(q)$ is the magnetic structure-factor correponding to the correlation between magnetic moments of the particles and $\gamma(q) = (2/3)P_M(q)/P_N(q)$ is the ratio of their magnetic and nuclear form-factors (see inset in Fig.1, *b*).

For double layer sterically stabilized ferrofuids on polar carriers the structure-factor effect is quite different in comparison with the non-polar ferrofluids. In the case of highly stable ferrofluids (e.g. pentanol) the interaction is close to that of hard spheres (Fig. 2). The scattering can be fitted [2] using Vrij's formalism [3] up to the magnetite volume fraction of 5 %. A further concentration increase results in softening of the repulsion potential, which is in agreement with properties of the second surfactant layer (physical adsorption). For less stable samples (water, methyl-ethyl-ketone [4]) the interaction results in appearance of fractal or elongated clusters whose structure does not depend much on the magnetite concentration but is sensitive to temperature [2].

Acknowledgments

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