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Field induced structures in colloidal solution of hexaferrite nanoparticles

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Plate-like strontium hexaferrite particles $SrFe_{12}O_{19}$ have an average size of 50 nm$\times$ 5 nm and coercive force of about 5000 Oe. When dissolved in water, these particles disperse in space with random orientations, but cause of anisotropic steric interactions readily turn and align in magnetic fields demonstrating a phase transition of isotropic-nematic liquid. We use the small angle polarized neutron scattering (P-SANS) technique to study the effect of a magnetic field on the structural ordering of the ferrofluid. The P-SANS experiments were performed at the VSANS facility of the Chinese Spallation Neutron Source (CSNS). The beam of neutrons polarized up to $P_0 = 0.95$ within a wavelength range from 0.22 to 0.67 nm was used. SANS patterns were taken for the sample having no magnetic prehistory and then exposed to the external magnetic field from 0.0005 to 0.9 T. The two dimensional maps of the SANS intensity reveal a diffuse isotropic scattering at small fields $H < H_c = 0.001$ T and a series of diffraction reflections appeared along the field axis ($H \gg H_c$) at $q_b, 2q_b, 3q_b$, where $q_b = 0.3$ nm^{-1}, which corresponds to the particle ordering at a distance of 21 nm, approximately. The nuclear-magnetic interference scattering obtained from the difference of intensities with a neutron spins parallel and antiparallel to magnetic field reveals two additional peaks in the direction perpendicular to the field at $q_\perp = 0.06$ nm^{-1}. It implies appearance of nematic ordering with the period of 100 nm. Thus, we conclude that upon magnetization process three structural states of the ferrofluid can be identified in different magnetic field regions. Long-range but disordered magnetic chains of hexaferrite particles are formed in a nonmagnetized sample at low fields $H < H_c$. These chains are transformed into structurally curved (spiral-like) structures oriented along the magnetic field at $H > H_c$. These spirals are broken into short strait columns of the 10-12 particles directed rigidly along the magnetic field at $H >> H_c$. The columns are organized in the nematic structure and its period decreases with increase of magnetic field. These findings are supported by the numerical simulations of the colloidal solution in magnetic field.

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