New ferrofluid composites: Magnetism and optics experiments

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NEW FERROFLUID COMPOSITES : MAGNETISM AND OPTICS EXPERIMENTS

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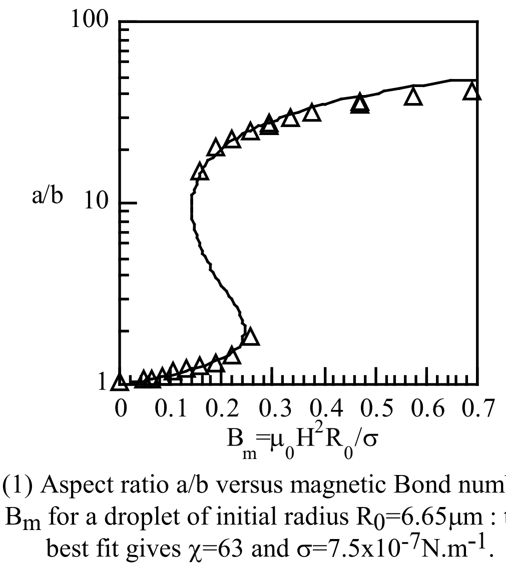
An ionic ferrofluid is an aqueous colloidal suspension of surface charged magnetic nanoparticles. Dispersion of the particles is ensured by the Coulomb forces. The effect of an added electrolyte is the screening of the electrostatic repulsions. Above a threshold ionic strength, a separation occurs between one phase rich in particles and another poor in particles [1]. Near the threshold, this ferrofluid composite consists of highly magnetic droplets (a few micrometers in diameter) surrounded by a dilute weakly magnetic medium. The nanoparticles are made of γ-Fe_2O_3 (maghemite) and their polydispersity is high : their diameter follows a log-normal distribution with parameters D_0=6.8nm and σ=0.5. Hence relatively large particles are present which favors phase separation. Iron titration of the concentrated phase gives a volume fraction of particles Φ_c=0.31.To characterise the microdroplets we use the method [2] which consists in measuring their ellipsoidal deformation (axisymmetric prolate ellipsoids with long semi-axis a and short semi-axis b) as a function of the magnetic field.



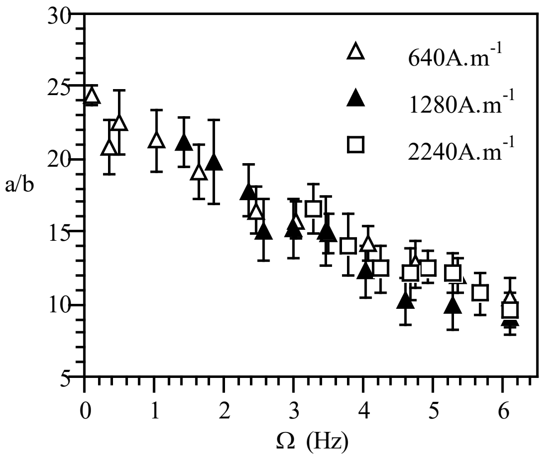
(1) Aspect ratio a/b versus magnetic Bond number B_m for a droplet of initial radius R_0=6.65µm : the best fit gives χ=63 and σ=7.5x10^{-7}N.m^{-1}.

The equilibrium shape results from the competition between magnetic and interfacial energy. Figure (1) shows the aspect ratio a/b for a droplet of given volume versus field intensity. The best fit gives the magnetic susceptibility χ=63 of the concentrated phase and the interfacial tension σ=7.5x10^{-7}N.m^{-1} between the two phases. Because of the high value of χ and the small value of σ a magnetic induction so small as a few 10^{-4}T induces a large deformation of the droplets.

(2) Picture of an assembly of microdroplets in a magnetic field with intensity H=1280A.m^{-1} rotating at frequency Ω=3.45Hz.

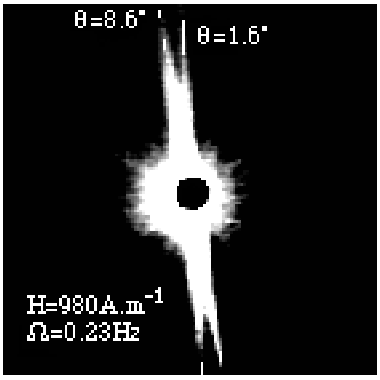
We study this magnetic composite material which consists in an assembly of magnetic and deformable microdroplets. We present here two complementary experiments in order to show the competition between the magnetic torque created by a field and the viscous torque due to a local vorticity. In the first experiment the assembly of microdroplets is submitted to a rotating magnetic field at frequency Ω and observed under an optical microscope. Figure (2) is a typical view for a field intensity H=1280A.m^{-1} and a frequency Ω=3.45Hz. The rotation is counter clockwise and the picture is taken at a moment when the field is along the vertical.

Thus there is a visible phase lag θ between the field and the droplets. The highest values of θ are found for the most elongated droplets. For a given droplet, θ increases with the frequency Ω. At a critical value Ω_c the droplet breaks into two parts or more in order to minimize the total dissipation [3]. Figure (3) shows the mean aspect ratio a/b of the droplets distribution as a function of Ω at constant field intensity and for several values of the field. The decreasing of the average aspect ratio with increasing Ω is a consequence of the break up of the droplets. Simultaneously the mean volume of the droplets decreases and the number of droplets in the screen increases to keep the total volume of concentrated phase constant.



(3) Aspect ratio a/b averaged on approximately 100 droplets versus Ω.

The second experiment consists in a rotating sample at frequency Ω in a static field H (H⊥Ω).The solid rotation of the cell under a constant field is equivalent to the rotation of the field with a static sample. We study the diffraction pattern of a laser beam parallel to Ω in order to obtain a direct measurement of the phase lag θ averaged on a huge amount of droplets. Figure (4) is a picture of the scattering pattern for $H=980A.m^{-1}$ and Ω=0.23Hz. There is a wide range of H and Ω where two scattering lines corresponding to two different values of θ are observed simultaneously.

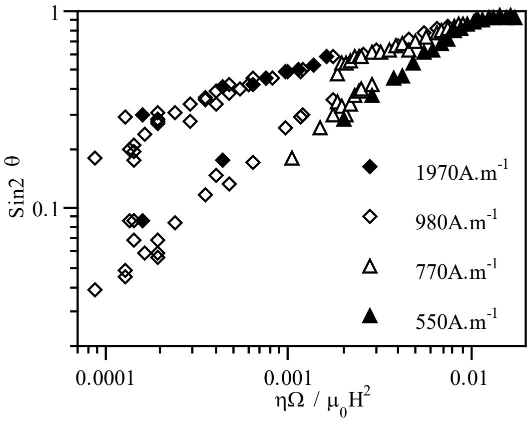


(4) Scattering pattern of an assembly of microdroplets in a sample rotating counter clockwise submitted to a static field.

Thus we deduce that the population of droplets is bi-modal, which can be a consequence of the break up of the droplets caused by the viscous torque. In a simple model for large aspect ratio and large χ, the balance between magnetic and viscous torques scales as :

$$\eta a^3 \Omega \propto \mu_0 \chi a b^2 H^2 \sin 2\theta$$

where η is the viscosity of the dilute phase. As it is expected the upper limit of θ is 45°. The plot on figure (5) of sin2θ versus Ω/H^2 allows to superpose all the data on only two branches.



(5) Plot of sin2θ versus Ω/H^2 for several H.

References

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[3] A. V. LEBEDEV and K. I. MOROZOV, *JETP Lett.* **65** 2 (1997) 161.