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SCATTERING AND DEPOLARIZATION OF POLARIZED NEUTRONS IN FERROFLUIDS

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Abstract

On the SPN - 1 polarized neutron spectrometer at IBR -2 high - flux pulsed rector there were carried out preliminary measurements on transmission and polarization of a neutron beam passing through a magnetic colloidal system of Fe_3O_4 particles in transformer oil and dodecane carriers. It was ~~find~~ found that in the ferrofluids with magnetite particles exist, dependent on the particle volume concentration and the magnitude of the external magnetic field, effects of depolarization and nuclear - magnetic small angle scattering.

Introduction

Magnetic colloids subjected to a magnetic field present a spatial and magnetic self - organization [1]. Recently there were overdone investigations with neutrons which have demonstrate that polarized neutrons can be used for studying the magnetic field microstructure inside the colloids [2,3, 4, 5].

The application of neutron depolarization started in 1941 by Halpern and Holstein [6] theoretically, and experimentally by Burgy et.al. [7] in 1950. Contrary to neutron scattering and small angle neutron scattering (SANS), the method has never developed into a wide-spread application. At present, neutron depolarization is exploited at a few places in the world [8 - 18].

The ferrofluids represent colloidal suspensions of single domain ferromagnetic particles of about 100A in diameter, stabilised with surfactant molecules, in a suitable liquid carrier. Therefore, though the particle sizes are distributed log - normally [19,20], it is permitted to assume that all the particles are spheres of the same radius.

Experiment description

The preliminary studies of the magnetic colloids presented in this report were carried out at the spectrometer of polarized neutrons (SPN -1), installed at the high - flux pulsed reactor IBR - 2 at the Joint Institute for Nuclear Research.

In Fig.1 is represented the schematic drawing of SPN - 1 [21]. The double disk chopper (Fig.1-**1**) suppresses the background from the satellite reactor pulses and also defines the neutron wavelength band from 0.7 to 12A. The chopper discs rotate in opposite directions with velocities which can be varied within the range from 5 to 20Hz.

The conical neutron guide (Fig.1-**2**), constructed from glass plates coated by evaporation method with nikel, forms the neutron beam before the polarizer and increases the effective aperture of the instrument. The basic spectrometer components are two five meter long bent neutron guides (Fig.1-**3**), polarizer and analyzer, assembled from iron - cobalt magnetic mirrors containing a titanium - gadolinium antireflecting sublayer. Incident beam polarization is provided using the first neutron guide. The polarization efficiency of the beam, averaged over the thermal neutron spectrum (the maximum of the

Maxwellian distribution of neutron flux is at 1.1A, λ = 0.7 - 12A), is about 95%. An appropriate static guide field in the polarized incident beam is provided by permanent magnets generating a magnetic field of about 120Oe.

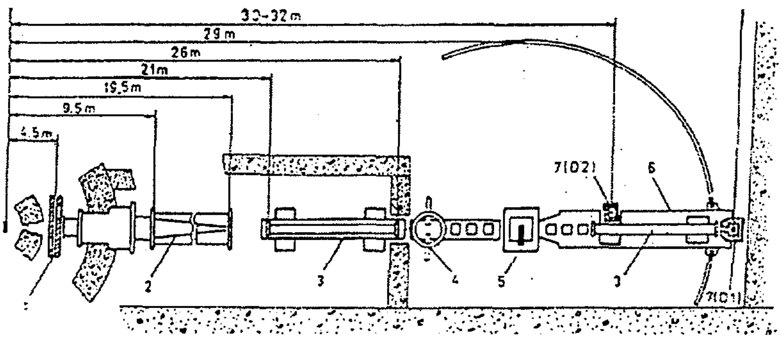

Fig.1 SPN - the polarized neutron spectrometer at IBR -2
1) double disk chopper; 2) conical neutron guide; 3) polarizer and analyzer; 4) neutron spin - flipper; 5) sample; 6) turn - table; 7) detector.

The neutron spin - flipper (Fig.1-4) is a non - adiabatic one [22] reversing the neutron beam polarization over the whole wavelength band with an efficiency of order of 95% at a beam cross section of $2.5 \times 60mm^2$.

The maximum integral neutron flux at the polarizer exit is 1.2×10^6n/sec cm^2. The horizontal collimation of the incident beam can be varied in the range $\Delta\theta_{min} = 3 \times 10^{-5}$ rad up to $\Delta\theta_{max} = 3 \times 10^{-4}$rad. This fact permits by measuring the transmission of neutrons through the sample to collect (to record) the neutron scattering from particles smaller than 10μm (on a sample of 0.1mm × 50mm dimensions the neutron flux is 500 - 5000n/s).

The sample position is located at 29 meters from the source. The sample (Fig.1-5) is fixed at the turn - table (Fig.1-6).The sample can be settled in a gap of turning magnets. The direction of the applied magnetic field can be changed to make an angle with the sample surface. The maximum magnetic field value is 10kOe.

The sample - detector distance is 7.5meters. The transmitted neutrons are counted by a ^{3}He gas - filled detector (Fig.1-7).

In the experiment we measured P(H), as neutron - beam polarization at the outlet of the analyser when the neutron beam is transmitted through the sample and separately P_0(H), as neutron - beam polarization at the outlet of the analyser when the neutron beam is transmitted through an empty sample holder, as :

$$P(H,\lambda) = [R(H,\lambda) - 1]/[R(H,\lambda) + 1],$$

where $R = I_{off}/I_{on}$, and I_{off} and I_{on} are the integral intensities over the (0.5 - 15)A wavelength range as registered by the neutron detector when the spin - flipper is off and on, respectively. P_0 is the multiplication between p_1 and p_2, where p_1 and p_2 represents the polarizing efficiency of the polarizer, respectively of the analyser. From the reflected intensities into the detector after several calculations is obtained the quantity characterizing the depolarization process in a sample: P/P_0. There were analysed also the normalized intensity of neutrons:

$$I = (I_{on} + I_{off}) / I_{on,0} + I_{off,0})$$

The measurements were performed on two kind of samples: Fe_3O_4 particles in transformer oil (Fig.2 - 4) and dodecane (Fig. 5 - 6) carriers. During the experiments the ferrofluids were kept in aluminium holders of disc form of 30mm in diameter and 3mm thikness, with the axis oriented along the neutron beam. The holder with the sample was situated between the poles of an electromagnet generating a vertical oriented magnetic field. In the case of the first sample there was used an electromagnet with an intensity of the magnetic field variable in the range of (0 - 4)kOe. The cross section of the poles of the electromagnet and the distance between them were 20mm × 60mm and 60mm, respectivelly. In the case of the second sample there was used an electromagnet with an intensity of the magnetic field variable up to 600Oe. The cross section of the poles of this electromagnet and the distance between them were 30cm × 30cm and 25cm, respectively.

Experimental results

Fig.2 presents the plot of the normatted intensity of transmitted neutrons $(I_{on} + I_{off})/(I_{on,0} + I_{off,0})$, expressed in n/st (starts represents the number of pulses of the reactor and is considered as a unit of time), versus the magnitude of the external magnetic field in the range of (0 - 3.6)kOe for the case of 17.5% particle volume concentration. For the magnitude H = 130Oe of the magnetic field, it can be seen a minimum of the intensity, which corresponds to the rising of the neutron scattering. The analysis of the scattering intensity dependence versus the wavelength indicates that the scattering cross - section arise with the growing of the wavelength. This scattering represents a small angle scattering from magnetic - nuclear inhomogenities of the fluid. Indeed, with the rising of the wavelength is turning smaller the limit of minimum value of the scattering vector . Over this minimum value the neutrons are scattered. In conection with this fact, because of the range extension of the scattering vector the integral on scattering vector of the scattering cross - section rises.

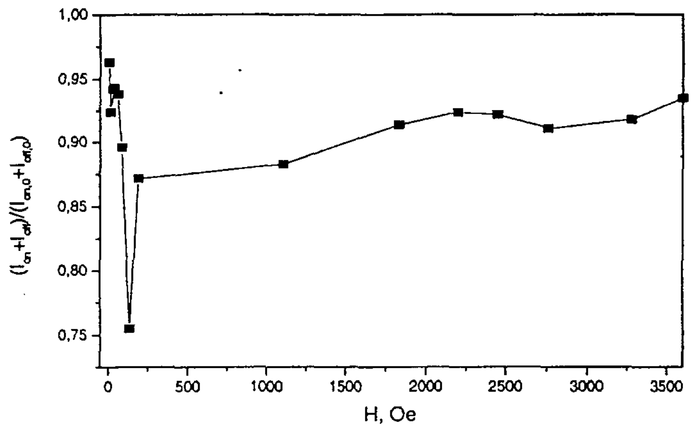

Fig2.The normatted intensity of transmitted neutrons, expressed in n/st, versus the magnitude of the external magnetic field.

From Fig.2 and the dependence of the normatted intensity (for the spin -flipper "off" and "on" versus the wavelength of neutrons for three values of the magnetic field: 87.3 Oe; 130.5Oe; 191 Oe we saw that the scattering from positive spin state is bigger than those corresponding to the negative spin state. This means that there is an interference between the nuclear and magnetic scatterings. Thus the intensity of the magnetic field is bigger in the region of the ferrofluid where the changing of the nuclear potential over its medium value is positive. For the wavelength of 2A the scattering of the negative spin state represents 15% and of positive state 25%. One can conclude from this that the variation of the magnetic potential represents 12.5% from the magnitude variation of the nuclear potential. From the variation of the nuclear potential (nuclear contrast) it can be determined the variation of the intensity of the magnetic field. From the experiment geometry it can be determined the value of the magnetic correlation length. In our case it is about 300A. This value is 3 times bigger than the particles diameter. So, this means that there exists the aggregation in clusters containing tens of particles. The existence of big clusters is proved by the fact that the sample reached the magnetization saturation at small values of the magnetic field intensity, about 3Oe.

For bigger values of the magnetic field intensity the scattering decreases, fact explained by the lowering of the magnetic contrast between the clusters and the inter-clusters distances. In the case of the intensity of the magnetic field of 130Oe the magnetic contrast is maximum and this determines a maximum magnetic - nuclear scattering and the lowering of the polarization of the transmitted neutrons.

In the second part of the experiment is studied the dependence of the beam polarization of the transmitted neutrons versus the intensity of the magnetic field in the case of five different particle volume concentrations in dodecane: 20%; 16.92%; 16%; 15.56%; 10.52%. We have noticed that the maximum effect of depolarization appears for the maximum concentration of 20%. Also, the big changing of the depolarization - 9 times for a 2 times lowering of the particle concentration, demonstrates that this changing is due mainly to the changing of the perpendicular component of the magnetic induction in the ferrofluid for about 3 times.

Further, we saw that for big values of the intensity of the magnetic field normalized polarization overgrows the unity. This effect reaches the maximum for the volume particle concentration of 16% and 10%. For this values of concentration this effect is revealed beginning from the intensity of the magnetic field of 25Oe. For other concentrations this effect is revealed at bigger intensity values of the magnetic field. It is clear that, at this point there is a competition in between the interactions between the magnetic moments and the magnetic moments with the magnetic field. As a result, there is reached a configuration of the orientations of the magnetic moments, which involves a particular correlation function distribution of the magnetic and nuclear potentials of the neutron scattering. Consequently, this leads to a specific neutron scattering law.

There is necessary to point out, that in contrast to the measurements overdone on ferrofluids based on transformer oil, for the ferrofluids based on dodecane there is obtained a rising of the intensity of the magnetic field in the regions which presents a negative variation of the nuclear potential relative to its medium value

Conclusions

This preliminary experiments have shown that the methods of depolarization and small angle scattering can be successfully used for the study of the magnetic structure of the interactions between the magnetic moments. There was find, that in the ferrofluids with magnetite particles there exist, dependent on the particle volume concentration and the magnitude of the external magnetic field, different effects of magnetic aggregation. Also there are obtained magnetic and nuclear correlations of different sign of the neutron scattering density.

Further investigations using a sensitive - position detecting method of the neutrons will permit detailed studies of the particles behaviour in ferrofluids.

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