The influence of dielectric permittivity of the medium on magneto-optical properties of the magnetite ultrafine structures.

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Abstract. In our research, the influence of dielectric permittivity of the medium $\varepsilon_0$ on magneto-optical properties of the magnetic ultrafine structures has been evaluated on the example of the magnetite magnetic fluids. Calculations, obtained by using the correlation analyses method, showed that the influence of $\varepsilon_0$ on the amount of the frequency dependences equatorial Kerr effect is 37%. We would like to underline that this result will be also suitable to all the magnetic ultrafine medium, the optical constants, n and k, of which are in relation $n^2 = k^2$. Besides, this result gives a really good opportunity to forecast the magneto-optical properties of the ultrafine medium and therefore to receive the proper parameters of ultrafine medium.

1. Introduction
Nowadays, the magneto-optical reflection effects are successfully used to study the processes in the surface regions of magnetic fluids. By these methods it has been revealed that the application of an external magnetic field to the magnetic fluids causes changes in the concentration of magnetic particles in the magnetic fluids' surface region, creates the surface layers, magnetized opposite to the external magnetic field, stimulates the surface lamination of the magnetic fluids [1, 2].

In considering the magneto-optical effects, which are odd functions of magnetizations in magnetic fluids, it should be kept in mind that magnetic fluid is a variety of the ultrafine medium in which magnetic colloidal particles have many degrees of freedom.

The magneto-optical properties of ultrafine media were analyzed in refs. [3-5] where it was shown that in considering the magneto-optical properties of a medium consisting of magnetic colloidal particles the sizes of which are much less than the light wavelength, one should introduce the tensor of the effective dielectric permittivity

$$
\varepsilon = \begin{pmatrix}
\varepsilon_{eff} & i\varepsilon'_{eff} & 0 \\
-i\varepsilon'_{eff} & \varepsilon_{eff} & 0 \\
0 & 0 & \varepsilon_{eff}
\end{pmatrix},
$$

(1)

where $\varepsilon_{eff} = \varepsilon_{1eff} - i\varepsilon_{2eff}$; $\varepsilon_{aeff} = \varepsilon_{0eff} + i\varepsilon_{2eff}$ and $\varepsilon'_{eff} = \varepsilon'_{1eff} - i\varepsilon'_{2eff}$.

In this case the tensor components depend on both the properties of magnetic colloidal particles themselves and the properties of the medium in which they find themselves.
2. Theory
For magnetic fluids with low concentration of magnetic colloidal particles and with no direct contact between them, the tensor components of the effective dielectric permittivity within the frames of theoretical models of an effective medium, extended to the case of magnetic media, can be written as:

1. The model of averaged characteristics:

\[ \varepsilon_{\text{eff}} = q \varepsilon_m + (1 - q) \varepsilon_f; \quad \varepsilon_{\text{eff}}' = q \varepsilon_m' \]  

(2)

2. The Maxwell Garnett model:

\[ \varepsilon_{\text{eff}} = \frac{2q(\varepsilon_m - \varepsilon_f) + (\varepsilon_m + 2\varepsilon_f)}{(\varepsilon_m + 2\varepsilon_f) - q(\varepsilon_m - \varepsilon_f)}; \quad \varepsilon_{\text{eff}}' = \frac{9q\varepsilon_f^2 \varepsilon_m'}{(\varepsilon_m(1 - q) + \varepsilon_f(2 + q))^3} \]  

(3)

3. The Bruggeman model:

\[ \varepsilon_{\text{eff}} = \varepsilon_e(1 + 3q \frac{\varepsilon - \varepsilon_o}{\varepsilon + 2\varepsilon_o}); \quad \varepsilon_{\text{eff}}' = \frac{9q\varepsilon_e^2 \varepsilon'}{(\varepsilon + 2\varepsilon_o)^3} \]  

(4)

where \( \varepsilon_m = \varepsilon_{1m} - i\varepsilon_{2m} \) and \( \varepsilon_m' = \varepsilon_{1m}' - i\varepsilon_{2m}' \) are the diagonal and nondiagonal tensor components of the dielectric permittivity of the material of magnetic colloidal particles, \( \varepsilon_f \) is the dielectric permittivity of the fluid phase, and \( q \) is the ratio of the volume, occupied by magnetic particles, to the total volume of the magnetic fluid.

The equatorial Kerr effect consists in a change in the intensity of linearly polarized light reflected from the sample in the case of reversal of magnetization. It can be written

\[ \delta_e = \frac{I_H - I_{H=0}}{I_{H=0}}, \]  

(5)

where \( I_H \) and \( I_{H=0} \) are the intensities of light reflected from the magnetized and demagnetized sample, respectively.

The equatorial Kerr effect, like the other magneto-optical effects which are odd functions of magnetization, occurs only in the presence of a ferromagnetic phase in the medium under investigation and is related to the tensor components of the effective dielectric permittivity as follows

\[ \delta_e = \frac{2 Sin 2\varphi (A \varepsilon_{1\text{eff}}' + B \varepsilon_{2\text{eff}}')}{A^2 + B^2} \]  

(6)

where \( A = \varepsilon_{2\text{eff}}' (2\varepsilon_{1\text{eff}}' \cos^2 \varphi - 1) \) and \( B = (\varepsilon_{2\text{eff}}' - \varepsilon_{1\text{eff}}') \cos^2 \varphi + \varepsilon_{1\text{eff}}' - \sin^2 \varphi \)

where \( \varphi \) is the angle of light incidence on the sample.

3. Methods
In general, magneto-optical properties of magnetic fluids are very different from the properties of bulk ferromagnetics. This fact causes the changes in spectral and angular dependences of magneto-optical effects. This occurs because magnetic fluids represent an example of ultrafine magnetic medium composed with magnetic particles, the sizes of these magnetic particles surrounded by the carrier fluids, are much less than the light wavelength. Therefore, it is important to define the
conditions of magneto-optical experiment. In this case it occurs much easier to interpret the magneto-optical spectrums, that provides information on magnetized magnetic fluids surface layer, electronic energy structure of fine magnetic particles and the properties of carrier fluids. Besides, it is significant to examine the electronic energy structures of fine magnetic particles, to investigate not only the temporary stability of magnetic fluids, but also to analyze the chemical processes on the surface of the magnetic particles. On the other hand, in some cases the fine magnetic particles could be used as a probe.

In reference [3] the Maxwell-Garnett theory was generalized to the case of magnetic media and an expression for the equatorial Kerr effect $\delta_e$ was obtained. It provides information on both the magnetic properties of magnetic fluids and the electronic energy structure of fine magnetic particles. It was shown that in the most general case the character of the frequency and angular dependences of $\delta_e$ is determined by the ratio of the volume occupation $q$ of a magnetic fluid by magnetic particles.

In reference [6] the equatorial Kerr effect is represented within the theoretical Maxwell-Garnett model. A theoretical analysis has shown that in the case of magnetic oxides, for which the condition $n^2 - k^2$ is fulfilled, the equatorial Kerr effect $\delta_e(q)$ for magnetic fluids with the ratio of the volume occupied by magnetic particles is related to the equatorial Kerr effect $\delta_m$ on the material of particles by the following simple relation

$$\delta_e(q) = q \delta_m$$  \hspace{2cm} (7)

From the relation obtained it follows that in the case of magnetic oxides the character the spectral dependences of magneto-optical effects are similar for the magnetic fluids and for the substance of particles. The experimental and theoretical results for the magnetite magnetic fluids are in good agreement.

On the example of magnetite magnetic fluids in reference [7] it was decided to evaluate the percent of the influence of $q$ on the variation of the frequency dependences equatorial Kerr effect comparing to other factors. Calculations showed that the influence of only $q$ factor on the amount of the frequency dependences equatorial Kerr effect is 53%.

4. Results and discussion

Another significant factor that influences magneto-optical properties of magnetic fluids is dielectric permittivity of the medium $\varepsilon_0$. We have evaluated its impact on magneto-optical properties of ultrafine medium by using correlation analyses method. According to the rule of dispersion summarizing, total dispersion $\sigma_o^2$ is the sum of the arithmetic meaning group dispersion $\overline{\sigma^2}$ and inter-group $\delta^2$ dispersions. This relation is expressed by the formula:

$$\sigma_o^2 = \overline{\sigma^2} + \delta^2$$  \hspace{2cm} (8)

The total dispersion $\sigma_o^2$ shows which part of the total variation is defined by the sign of the present grouping [7].

The experimental data have been used from the papers [1, 6], where frequency dependences (the angle of light incidence on the sample $\phi=70^0$) equatorial Kerr effect for the magnetite magnetic fluids with different carrier fluids (oil, water, kerosene) and its sediments are measured. The present work help us to group experimental data by using the changes in $\varepsilon_0$. Calculations were implemented to the incident light quantum energy $h\omega=2,0$ eV.

The experimental data taken from [1, 6] are shown in table 1.
Table 1. Experimental data from Refs. [1, 6]

|            | $\varepsilon_0$ | $\delta_\varepsilon(q)$ for various q |
|------------|-----------------|--------------------------------------|
| oil        | 0.36 - $10^{-3}$| 0.30 - $10^{-3}$ 0.39 - $10^{-3}$ |
| water      | -0.17 - $10^{-3}$| -0.32 - $10^{-3}$ 0.05 - $10^{-3}$ |
| kerosene   | 0.20 - $10^{-3}$| 0.25 - $10^{-3}$ 0.15 - $10^{-3}$ |
| air        | 1.10 - $10^{-3}$| 0.28 - $10^{-3}$ 0.80 - $10^{-3}$ |

According to the calculations part of influence of $\varepsilon_0$, is 37% comparing to other factors (the size of the particles, the order of the particles, magnetic particles concentration and others). We would like to underline that this result will be suitable also to all the magnetic ultrafine medium, the optical constants, $n$ and $k$, in which are in relation $n^2 \quad k^2$.

5. Conclusions
In our research, the influence of dielectric permittivity of the medium $\varepsilon_0$ on magneto-optical properties of magnetic ultrafine structures has been evaluated on the example of the magnetite magnetic fluids. Calculations, obtained by using the correlation analyses method, showed that the influence of $\varepsilon_0$ on the amount of the frequency dependences equatorial Kerr effect is 37%. This result gives a really good opportunity to forecast the magneto-optical properties of the ultrafine medium and therefore, to receive the proper parameters of ultrafine medium.

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