MAGNETISATION OF NANOPARTICLES OF MAGNETITE WITH MAGNETIC DIPOL-DIPOL INTERACTION IN DISPERSE MEDIUMS

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The potential of magnetic dipol-dipol interaction of magnetite nanopaticles has been described by expression: $E_{d-d} = -\frac{m^2}{4\pi\mu_0 r^3}\left(cth\frac{mH}{kT} - \frac{1}{\frac{mH}{kT}}\right)^2$. Magnetisation and magnetic susceptibility expressions for magnetic dipol-dipol interacting systems of magnetite nanoparticles has been obtained. Magnetisation and magnetic susceptibility curves determined by experimental and by means of obtained equations are good agree. Initial magnetic susceptibilities determined by numerical differentiation of experimental magnetisation curve and by means of obtained equations are 0.112, 0.0945 correspondingly. It has been established, that magnetic dipol-dipol interaction help to formation of chains of magnetic nanoparticles, along external magnetic fields line and magnetisation occurs by the method "parallel" mechanism magnetisation of chains.

1. INTRODUCTION

Investigation of the magnetisation of samples -I and -II (samples -I, -II are medium of magnetite nanoparticles with average geometrical size of nanoparticles 9.48 nm and 7.77 nm correspondingly) obtained from the experiments and calculated by means of Langevan equation showed, that at magnetisation region H=0-300 kA/m they don't agree and value of $(M_{exp.}-M_{theor.})/M_{exp.}=\Delta M/M_{exp.}$ changes in interval 0.945-0.055 and 0.458-0.056 for samples -I, -II correspondingly. The dependence $\Delta M(H)$ on tension magnetic field has been investigated by means of the square root method and it has been shown, that at weak magnetic field it increases, at middle field it is hyperbolic correlation and it increases with decreasing of magnetic field. The dependence ΔM(H) on concentration of magnetite nanoparticles is parabolic. Experimental and calculated initial magnetic susceptibilities of samples -I and -II at magnetite nanoparticles concentration 0.007, 0.0047 correspondingly are equal to 0.112, 0.0423 and 0.0102, 0.00011. Maximum magnetic diameter of nanoparticles of sample -I calculated by means of experiment is $\left(d = \left(\frac{18\chi_0 kT}{\pi M_0}\right)^{1/3} \right)$ and theoretical magnetic susceptibilities obtained from expressions of the difference geometrical size and nonmagnetic layer ($d=d_g$-0.839 nm) are 17.569, 8.0303, 16.73 correspondingly.

The correlation of energies of external magnetic fields ($E_{m-H}=mH$) and magnetic dipol-dipol interaction $E_{d-d} = \frac{m^2}{r^3}$ showed, that at concentration $\varphi_m \geq \frac{3H}{4\pi M_0}$ $\left(\varphi_m = \left(\frac{r_0}{r}\right)^3 \right)$, where r_0 is magnetic radius of nanoparticles, r is distance between centres of magnetite nanoparticles) $E_{d-d}=E_{m-H}$ and it is sufficient at weak and middle magnetic fields. Numerical analysis of correlation of energies of external magnetic field and magnetic dipol-dipol interaction of magnetite nanoparticles at changing tension of external magnetic field in 0-300 kA/m has been carried out. It is established that at weak and middle magnetic fields magnetisation occurs by the expense magnetite nanoparticles in large size and shown, that at weak and middle magnetic fields the correlation value is significant and equal to 11.24, 2.57 correspondingly for medium-I at concentration of magnetite nanoparticles φ_m= 0.007, 0.0048.

Numerical calculation of magnetisation and initial magnetic susceptibility of our mediums on the base of expressions indicated in [1-3] showed, that these value is essential less than (0.04235) [1] or more than (0.194) [2].

2. RESULTS AND DISCUSSION

Taking into account the results of analysis of experimental and calculated magnetisation we established, that magnetic dipol-dipol interaction of magnetite nanoparticles and the magnetic dipol-dipol energy depend on the orientation of magnetic dipoles, which depend on external magnetic field value. We suggested, that dipoles of all magnetic nanoparticles are oriented to along external magnetic field line even at weak magnetic fields and the dependence of energy magnetic dipol-dipol interaction of magnetite nanopaticles on the orientation of particles and of external magnetic field values in first approximation is determined by Langevan equation:

$$E_{d-d} = -\frac{m^2}{4\pi\mu_0 r^3}\left(cth\frac{mH}{kT} - \frac{1}{\frac{mH}{kT}}\right)^2 .$$

This expression has been substituted in statistical sum of system of magnetite nanoparticles, that statistical sum consists from the production of two statistical sums. The first part of statistical sum is statistical sum of noninteracting magnetite nanoparticle system, obtained by the Langevan equation. Second part of statistical sum is:

$$Z_2 = \int_{\Omega_2} \exp\left(\sum \frac{m^2}{4\pi\mu_0 r^3} \left(cth \frac{mH}{kT} - \frac{1}{\frac{mH}{kT}} \right)^2 \right) d\Omega_2 .$$

The second part of statistical sum has been expanded in Taylor's set and taken into consideration first two terms. After integration over all volume and consideration the integral for two interacting particles, we take into account, that number twice interactions in unit volume is equal to $\frac{N(N-1)}{2}$, at N>>1 to $\frac{N^2}{2}$, and then we obtain:

$$Z_2 = 1 + \frac{N^2}{2V^2} \int_{V_j}\int_{V_i} \frac{m^2}{4\pi\mu_0 r^3} \left(cth \frac{mH}{kT} - \frac{1}{\frac{mH}{kT}} \right)^2 dV_i dV_j .$$

Last configuration integral has been taken in the centre of one of interacting nanoparticles and use following formulas

$$\Phi_2 = -kT \ln Z_2, M_2 = -\frac{d\Phi_2}{dH}, \chi_{20} = \left.\frac{dM_2}{dH}\right|_{H\to 0}$$

and $\varphi_m = NV_o$ for obtaining following expressions for additional terms of the magnetisation and initial susceptibility of interaction of medium of magnetite nanoparticles:

$$M_2 = \frac{1}{3} M_s^2 \varphi_m^2 \frac{1}{\mu_0 H} \ln\left(\frac{VM_s}{m}\right) \left(cth \frac{mH}{kT} - \frac{1}{\frac{mH}{kT}} \right) \left(-\frac{mH}{kT} csc\, h^2 \frac{mH}{kT} + \frac{1}{\frac{mH}{kT}} \right),$$

$$\chi_{20} = \frac{1}{27} M_s^2 \varphi^2 \frac{1}{\mu_0} \ln\left(\frac{VM_s}{m}\right) \left(\frac{m}{kT}\right)^2 .$$

In fig. The magnetisation curves obtained by 1 - experiment, 2 - Langevan equation and 3 – considerated additional term are presented. Numerical analysis of magnetisation expression showed, that at changing magnetic field in 0-300kA/m, $\Delta M/M_{exp}$ changes at 0.836-0.026 and 0.109-0.058 for samples -I and -II correspondingly. Additional term of the magnetisation is sufficient at weak and middle magnetic fields and at large magnetic fields it leads to zero. Initial magnetic susceptibilities are determined by above mentioned expressions are 0.0945 and 0.0189 for samples -I and -II correspondingly. The suggested model is the generalisation one of models of pair sphere [1], effective volume [2].

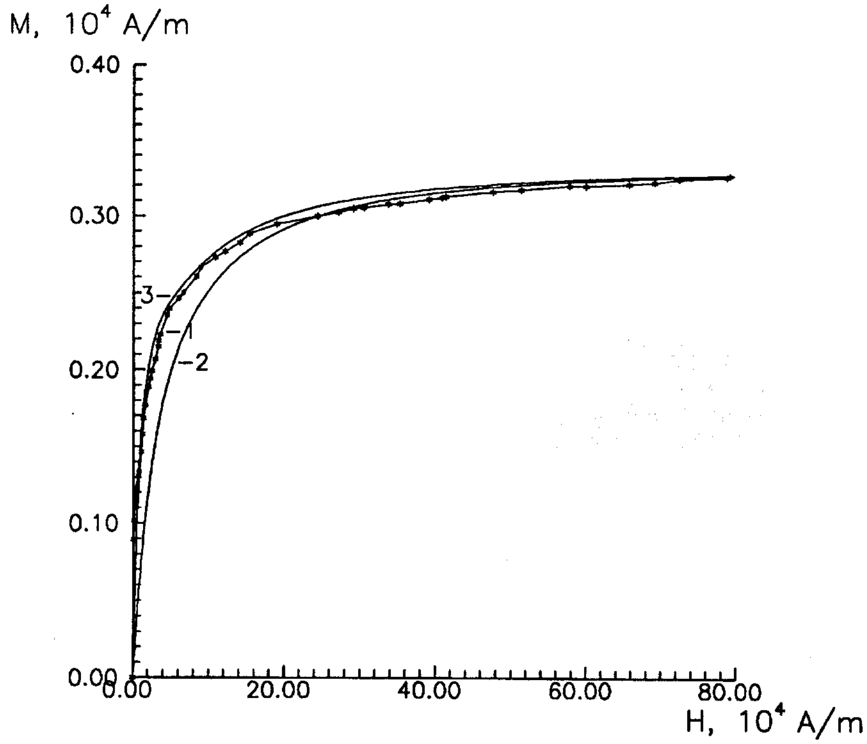

Fig. Magnetisation curves of sample-I obtained by 1 - experiment, 2 - Langevan equation and 3 - additional term.

The maximum of the additional term of the magnetisation has been determined by Nuton method and it has been shown, that at $x=1.566$ $\left(x = \frac{mH}{kT}\right)$ the additional term of magnetisation has maximum. The value of maximum is linear function of magnetic moments and parabolic function of concentration of magnetite. The values of experimental and calculated magnetic field corresponding to maximum for sample-I are $1.19\cdot10^4$ A/m and $1.25\cdot10^4$ A/m correspondingly.

Analysis of curves of magnetic susceptibility of medium obtained by numerical differentiation of experimental curves of magnetisation and by analytical differentiation of expression obtained by us correspond with each other. Analysis of this curves showed, that magnetisation don't occurs uniform, that it's related with dispersity of system or magnetic dipol-dipol interaction of magnetite nanoparticles. At initial part of magnetisation average value of magnetic moment is maximal and at magnetisation it is approach to average value of magnetic moment of medium. At magnetisation time quantity of magnetic nanoparticles taken part in magnetisation increase. Certain section of magnetic susceptibility curves of magnetite nanoparticles is responsible some size or near size of magnetite nanoparticles. Decreasing part of curves is characterised by small size magnetite nanoparticles in magnetisation. Magnetic dipol-dipol interaction assisted to formation of chains, of magnetic nanoparticles which construct along external magnetic fields line and consequently magnetisation of medium occurs by the "parallel" mechanism method of the magnetisation of chains.

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R.Ə. Əli-zadə

MAQNİT DİPOL-DİPOL QARŞILIQLI TƏ'SİRDƏ OLAN NANOÖLÇÜLÜ MAQNETİT ZƏRRƏCİKLƏRİNİN DİSPERS SİSTEMLƏRDƏ MAQNİTLƏŞMƏSİ

Nanoölçülü maqnetit zərrəciklərin dipol-dipol qarşılıqlı tə`sir potensialı

$$E_{d-d} = -\frac{m^2}{4\pi\mu_0 r^3}\left(cth\frac{mH}{kT} - \frac{1}{\frac{mH}{kT}}\right)^2$$

tənliyi vasitəsilə ifadə olunmuşdur. Maqnit dipol-dipol qarşılıqlı tə'sirdə olan maqnetit nanozərrəciklər sisteminin maqnitləşmə və maqnit həssaslığı tənlikləri alınmışdır. Eksperimental və bu tənliklərdən alınmış maqnitləşmə və maqnit həssaslığı əyriləri yaxşı uyğunlaşırlar. Eksperimental maqnitləşmə əyrisinin ədədi differensasiyasında və bu tənliklərdən alınmış sistemin başlanğıc maqnit həssaslığı uyğun olaraq 0,112 və 0,0945 bərabərdir. Göstərilmişdir ki, maqnit dipol-dipol qarşılıqlı tə'siri maqnetit nanozərrəciklər zəncirinin xarici maqnit sahəsinin qüvvə xətləri istiqamətində yönəlməsinə kömək edir və maqnitləşmə nanozərrəciklərinin "paralel" maqnitləşmə mexanizmi ilə baş verir.

Р.А. Али-заде

НАМАГНИЧИВАНИЕ НАНОЧАСТИЦ МАГНЕТИТА С ДИПОЛЬ-ДИПОЛЬНЫМ ВЗАИМОДЕЙСТВИЕМ В ДИСПЕРСНЫХ СРЕДАХ

Потенциал магнитного диполь-дипольного взаимодействия наночастиц магнетита описан выражением

$$E_{d-d} = -\frac{m^2}{4\pi\mu_0 r^3}\left(cth\frac{mH}{kT} - \frac{1}{\frac{mH}{kT}}\right)^2$$

Получены уравнения намагничивания и магнитной восприимчивости систем наночастиц магнетита с магнитным диполь-дипольным взаимодействием. Кривые намагничивания и магнитной восприимчивости, определенные экспериментально и с помощью полученных уравнений согласуются. Начальные магнитные восприимчивости, определенные численной дифференциацией экспериментальной кривой намагничивания и с помощью полученных уравнений равны 0,112 и 0,0945 соответственно. Доказано, что магнитное диполь-дипольное взаимодействие помогает образованию цепочек наночастиц магнетита вдоль силовых линий внешнего магнитного поля и намагничивание происходит по "параллельному" механизму намагничивания цепочек.

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