New methods of the magnetic nanoparticles characterization

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The nanoparticles of the magnetic materials have received wide application in various spheres: biological researches and medicine where with their help transport of preparations in an organism of the patient is carried out, local heating of the amazed bodies by means of external fields etc. [1-3] is made. Rather recently it has been shown, that magnetic nanoparticles can represent itself as nano-markers with which help it is possible to make examination of authenticity of documents and their separate fragments [4], and also to carry out their protection [5,6]. These directions of researches are substantially connected with possibility to spend measurement of magnetic properties with extremely small quantities of a magnetic material. Ample opportunities for application magnetic nanoparticles are opened by that circumstance, that by change of the sizes, the form, structure and a structure it is possible to operate in certain limits their properties, including the magnetic. The problem of practical application is substantially defined by possibility of an establishment of reliable dependences of properties magnetic nano-materials from the size, the form, properties of possible coverings etc. particles, and also working out of the certificated methods of reception nanoparticles with the set parametres. Thus, realization of potential possibilities of new materials essentially depends on a condition of metrological maintenance of objects with the characteristic sizes 1÷100 nanometers.

At the heart of metrology magnetic nanoparticles lay, naturally, various physical methods of measurements. In these purposes are used: mass spectrometry (for fullerenes in particular), nuclear resonance (Mössbauer absorption spectroscopy), definition of the area of a nanopartcle's surface (on nitrogen adsorption), studying of a modular condition (X-ray analysis), size distribution of particles (light dispersion) and a number of others. The magnetic atomic force spectroscopy, SQUID magnetometer and resonant methods NMR and ESR –is applied to measurement of actually magnetic properties of nanoparticles.

In the present work, as one more method of measurement of magnetic parameters of the nanoparticles, the method of measurement of their magnetic moment is considered.

With that end in view we had been spent magnetization measurements of nanoparticles iron oxide Fe_3O_4 with addition of zinc, manganese and gadolimium in the various compositions which are looking like MFe_2O_4 (M = Mn, Zn, and Gd). In the given connection there is a replacement of ions of iron by ions of the specified metals. The investigated material is a superparamagnetic , the properties is close to paramagnetics though it is constructed from ferromagnetic clusters by the size less than 10 nanometers with the magnetic moment more than 1000 Bohr magnetons. On Figure.1 the dependences of the magnetic moment on an external magnetic field (M (H)) for the above-stated materials are shown. On dependences M (H) the hysteresis loops are absent, coercitive force is insignificant too, hence a superparamagnetic condition in nanoparticles is observed. On the basis of experimental data estimations, the effective magnetic moments of nanoparticles and numbers of the formular units falling on the one nanoparticle have been received. The specified magnetic moment μ_{eff} of nanoparticle was defined from Langevin's formula:

$$M(H)=N\mu_{eff}(cth(\mu_{eff}H/kT)-1/(\mu_{eff}H/kT)) \qquad (1)$$

Using μ_{eff} as the varied parameter, computer fitting of experimental curves and theoretical dependence (1) was made. Thus there were average values of the effective magnetic moment of one formula unit μ_{eff} (per formulas unit), the effective magnetic moment of one nanoparticle μ_{eff} in Bohr magnetons, the number of the formula units making one nanoparticle was estimated.

Fig. 1. The magnetic moment dependences on a magnetic field (M (H))
2-$Mn_{0.44}Zn_{0.78}Fe_2O_4$, 3 - $Mn_{0.58}Zn_{0.41}Fe_2O_4$, 4 -$Mn_{0.52}Zn_{0.44}$ $[Fe_{1.9}Gd_{0.09}]$ O_4, 5 -$Mn_{0.62}Zn_{0.10}$ $[Fe_{1.7}Gd_{0.26}]$ O_4, 6 - $Mn_{0.45}Zn_{0.45}$ $[Fe_{1.9}Gd_{0.09}]$ O_4, 7 - $Mn_{0.65}Zn_{0.33}$ $[Fe_{1.8}Gd_{0.17}]$ O_4, 8 - $Mn_{0.55}Zn_{0.16}$ $[Fe_{1.7}Gd_{0.27}]$ O_4, 9 - $Mn_{0.46}Zn_{0.40}$ $[Fe_{1.8}Gd_{0.19}]$ O_4,10 - $Mn_{0.42}Zn_{0.27}$ $[Fe_{1.7}Gd_{0.27}]$ O_4, 11- $Mn_{0.64}Zn_{0.39}$ $[Fe_{1.9}Gd_{0.09}]$ O_4, 12 - $Mn_{0.65}Zn_{0.23}$ $[Fe_{1.8}Gd_{0.19}]$ O_4, 13 - $Mn_{0.51}Zn_{0.54}Fe_2O_4$, 14 -$Mn_{0.45}Zn_{0.55}Fe_2O_4$

The received results are presented in Table 1. From the table follows, that the average of the formula units forming one nanoparticle of order 10^6, and its magnetic moment has an order 10^4 Bohr magnetons.

Table 1.

Composition	$Nx10^{19}$	μ_{eff} of the nanoparticle, in Bohr magnetons	Number of the formula units making one nano-particle $N_{nano}x10^6$
$Mn_{0.45}Zn_{0.45}$ $[Fe_{1.9}Gd_{0.09}]$ O_4	3,08	9959,39	0,995
$Mn_{0.65}Zn_{0.33}$ $[Fe_{1.8}Gd_{0.17}]$ O_4	3,71	6538,56	0,889
$Mn_{0.55}Zn_{0.16}$ $[Fe_{1.7}Gd_{0.27}]$ O_4	5,52	4503,38	0,782
$Mn_{0.46}Zn_{0.40}$ $[Fe_{1.8}Gd_{0.19}]$ O_4	24,52	5196,20	2,118
$Mn_{0.42}Zn_{0.27}$ $[Fe_{1.7}Gd_{0.27}]$ O_4	4,83	6322,05	1,768
$Mn_{0.64}Zn_{0.39}$ $[Fe_{1.9}Gd_{0.09}]$ O_4	4,72	12037,87	1,231
$Mn_{0.65}Zn_{0.23}$ $[Fe_{1.8}Gd_{0.19}]$ O_4	6,85	11604,86	1,137
$Mn_{0.62}Zn_{0.10}$ $[Fe_{1.7}Gd_{0.26}]$ O_4	5,89	9050,06	1,346
$Mn_{0.5}Zn_{0.5}Fe_2O_4$	4,60	12600,80	1,089
$Mn_{0.6}Zn_{0.4}Fe_2O_4$	5,13	14679,28	1,434
$Mn_{0.4}Zn_{0.6}Fe_2O_4$	6,36	4330,17	0,212
Fe_3O_4	15,71	15068,99	0,052
$Mn_{0.45}Zn_{0.55}Fe_2O_4$	8,51	11734,76	0,716

Let's notice, that the results received by us are in the good consent with other experimental researches of these nanoparticles.

The method of research offered by us easily extends on ferromagnetic and superparamagnetic nanoparticle, covered by passivating covering, for example from polymeric materials as it is used in medical applications [1,2], or the coverings arising naturally as a result of interaction with environment. Last circumstance is of interest for ecological researches of atmosphere of the closed and controllable rooms.

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