MAGNETIC BIAS AND THERMALLY INDUCED MAGNETIZATION REVERSAL IN THE RARE-EARTH ORTHOFERRITE

E.E. Zubov*

** G.V. Kurdyumov Institute for Metal Physics, NASU, 03680 Kyiv, Acad. Vernadsky Boulevard 36, Vasyl' Stus Donetsk National University, 021021, Vinnytsia, Ukraine, e-mail: eezubov@ukr.net*

Within the framework of a mean field theory the origin of a spin- reorientation transition, compensation point, magnetic bias and thermally induced spin reversal have been investigated for rare-earth orthoferrites. It is considered the most general case of two sublattice antiferromagnetic with exchange anisotropy and rare-earth - iron interactions. A small applied field appears to be a source of the additional anisotropy from canting of the sublattice moments. This anisotropy leads to imbalance of free energy for two types of domains. As a result we have a spin jump near the compensation point. A similar phenomenon is observed experimentally in the erbium orthoferrite.

To date many works were devoted to the theoretical interpretations of observed magnetic properties of orthoferrites. As rule, we have a phenomenology approach in the framework of Landau theory or method of quantum Hamiltonian. Unfortunately, in this cases the presence a large number of parameters and classic spin representation makes difficulties in the interpretations of the experimental results [1]. Now it is necessary the more exact analysis especially in the context of the new observed phenomenon of exchange bias in the erbium orthoferrite [2]. Also, in literature a such quantum- mechanical consideration so far is absent.

In this work the simple Hamiltonian of the Fe^{3+} and Er^{3+} ions with account for a weak anisotropic Heisenberg Hamiltonian with an easy axis along crystal *a* direction was used. The single one anisotropy is neglected since it is supposed that for Er^{3+} effective spin σ=1/2 and Fe^{3+} is in orbital *S*- state. Also, in crystal *ac* plane one can consider the Dzyaloshinsky-Moriya anisotropy with a single parameter *d* along *b* axis only. It is considered an area of the temperatures essentially above the ordering temperature of the rare-earth ions. That's why the effective Weiss field on the rare-earth sites is caused by iron subsystem only (R-Fe interaction) .

The unitary transform diagonalizing the Hamiltonian corresponds to ordinary rotation in three-dimensional spin space along *b* axis on the angles θ_i and φ for iron spin in *i*-th sublattice and erbium spin, respectively. It allows to write the total magnetic moment $M_{tot.}(\alpha,\tilde{T})$ of erbium orthoferrite in Bohr magnetons at temperature $\tilde{T}$ in units of intersublattice interaction $2J_{12}(0)$. The axis of antiferromagnetism *L* in general case is inclined to *a* by angle α. In what follows that the spin reorientation with rotation of *L* from α=0 to π/2=0 is realized only for strong anisotropy of the R-Fe interaction. In particular, in applied field *h* with anisotropy γ and canting angle θ_T caused by antisymmetric exchange of Fe^{3+} ions it follows

$$M_{tot.}(\pi/2,\tilde{T}) = g_{Fe}\sin(\theta_T) < \tilde{S}_z > -\frac{g_{Er}}{2}\tanh\left(\frac{\sin(\theta_T) < \tilde{S}_z > -2\gamma h}{2\gamma\tilde{T}}\right),$$

where $< \tilde{S}_z >$ is the mean spin of the Fe sublattice, $g_{Fe} = 2$ and $g_{Er} = 1.2$ are Fe^{3+} and Er^{3+} g-factors, respectively. Here, the canting angle satisfies to equation $\theta_T(2+b) = d + \frac{1}{4\gamma S}\tanh\left(\frac{S\theta_T}{2\gamma\tilde{T}}\right)$, where *b* is Heisenberg parameter exchange anisotropy in units $2J_{12}(0)$ and Fe^{3+} spin *S*=5/2.

In Fig.1 the temperature dependencies of total magnetic moment $M_{tot.}(\alpha,\tilde{T})$ in erbium orthoferrite are presented for different values of anisotropy of R-Fe exchange interactions. One can see that only at strong anisotropy γ≤1 of R-Fe exchange interaction the spin-reorientation phase transition is realized. It observed as a jump of $M_{tot.}(\alpha,\tilde{T})$. A good detailed point of compensation $\tilde{T}=\tilde{T}_{comp.}=0.194$ is seen for γ=0.7 after temperature $\tilde{T}=\tilde{T}_{SR}=0.419$ of spin reorientation. It is easy to find the critical temperature $\tilde{T}_C=2.92$ of the phase transition order–disorder. From the experimental value of the critical temperature 636 K we obtain $J_{12}(0)$=109 K, T_{SR}=92 K and $T_{comp.}$=42 K that is in good correspondence with measured temperatures 97 and 50 K [1,2] taking into account a such rough evaluation. In the linear approximation over h the free energy for domains type 1 and 2 with opposite directed L axes takes the forms, respectively: $\tilde{F}_1(\pi/2)/S^2=const+h\Delta M$ and $\tilde{F}_2(\pi/2)/S^2=const-h\Delta M$. Here, the magnetic bias ΔM is a result of additional increase θ_T by applied magnetic field h.

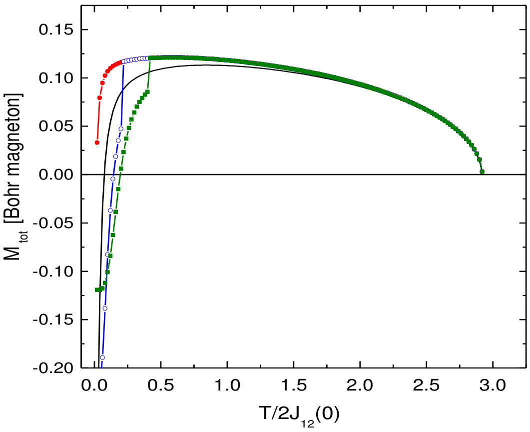

Fig. 1. The temperature dependencies of total magnetic moment in erbium orthoferrite at b=-0.001, d=0.05 and α=0, γ=10 (filled points), α=π/2, γ=2 (curve without points), α=π/2, γ=1 (open points) and α=π/2, γ=0.7 (filled squares).

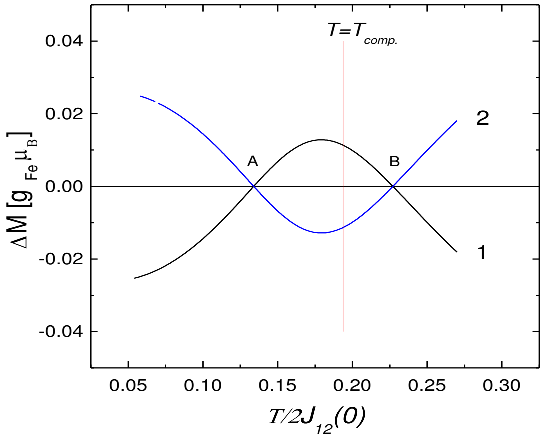

Fig. 2. Temperature dependences of the additional magnetic bias ΔM in an arbitrary small applied field h at parameters b=-0.001, d=0.05 and γ=0.7 with $\tilde{T}_{comp.}$= 0.194 (vertical line) for domain 1 and 2 (curves 1 and 2, respectively).

In Fig. 2 the dependence of ΔM on temperature T is presented for domains 1 and 2. One can see that ΔM for domains 1 and 2 near $\tilde{T}_{comp.}$ in knots A and B changes the sign. It causes the step-like overturns of the magnetic moments in those domains where the free energy gets the positive increase.

Thus, the experimentally observed step-like jumps for temperature dependences of $ErFeO_3$ magnetization near the compensation point are explained as a magnetic bias caused by additional deformation of the canting angle of Fe magnetic sublattice in a weak applied field.

The study was carried out within the Fundamental Research Programme funded by the MES of Ukraine (Project No. 0117U002360).

References

[1] K.P. Belov, A.K. Zvezdin, A.M. Kadomtseva, R.Z. Levitin, “Orientation transitions in rare-earth magnetics” (*in Russian*). Moscow: Nauka, 1979.

[2] I.Fita, A. Wisniewski, R. Puzniak, V. Markovich, and G. Gorodetsky. Phys.Rev., vol. 93.-pp. 184432-1-5, 2016.

[3] Ya.B. Bazaliy, L.T. Tsymbal, G.N. Kakazei, A.I. Izotov, and P.E. Wigen. Phys.Rev., vol. 69, pp.104429-1-10, 2004.