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PHENOMENOLOGICAL THEORY OF RELAXATION IN TWO-SUBLATTICE FERRITE

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The dissipative function of a two-sublattice ferrite was constructed. The relaxation times for the acoustic and optical branches of spin waves are calculated, as well as the relaxation times for the magnetization and antiferromagnetism vectors. The process of antiferromagnetism vector relaxation is shown to be the quickest one. The corresponding relaxation time is governed by the exchange relaxation constant and, due to the exchange interactions between atoms in the sublattices, becomes shorter owing to the dynamics of the antiferromagnetism vector. The process of ferrite magnetization relaxation is the slowest one. In the exchange approximation, the magnetization relaxation time tends to infinity, as the length of magnetization non-uniformities grows. The results obtained are compared with the experimental data on the relaxation phenomenon in GdFeCo alloy of rare-earth and transition metals.

K e y w o r d s: dissipative function of two-sublattice ferrite, relaxation times for the magnetization, relaxation times for the antiferromagnetism vector.

1. Introduction

There are a lot of trends in modern electronics and computer engineering concerning the application of magnetic materials, with the creation of systems for the data recording in computers remaining the most challenging task among them. The tendency of the further development involves the creation of devices characterized by a higher record density and a performance as fast as possible. In this domain, the optical normal record technique actually has no alternative, especially if modern femtosecond lasers are used. However, the problems aimed at the increase of the data record density can be solved by engaging exclusively the optical methods (near-field radiation systems, the application of laser emission in the violet spectral range). At the same time, the problem of information record and read-out rates in magnetic memory systems and the problem of information processing demand that fundamental problems in the dynamic physics of magnetism should be tackled.

In recent years, there emerged a new and promising direction in the physics of magnetism, which is based on a capability to manipulate the magnetization of magnets with the help of femtosecond laser pulses (see review [1]). This direction was coined as femtomagnetism [2], and many interesting results were obtained in its framework. The first experiments carried out using simple ferromagnetic metals demonstrated that the heating of metallic ferromagnets with a laser pulse gave rise to a rapid (within several picoseconds) change of the material magnetization [3]. Afterward, a possibility of non-thermal

excitation of spin oscillations in transparent magnets with the use of the inverse Faraday effect was marked [4], which determined the basic direction of progress in femtomagnetism for years [1]. So, if laser pulses with a duration of an order of 100 fs are used, oscillations with frequencies of up to terahertz range can be excited, which exceeds the magnetic resonance frequency inherent to uniaxial and rhombic antiferromagnets [5, 6]. This method allowed not only spin oscillations in both magnets with weak magnetism (like orthoferrites [7] or iron borate [8]) and pure antiferromagnets of the nickel-oxide type [9, 10] to be generated, but also nonlinear motion modes of the spin-reorientation type to be realized [11].

However, it turned out soon that the capabilities of thermal femtomagnetic effects were still not exhausted. Recently, an ultrafast (within several picoseconds) change in the directions of sublattice magnetizations was revealed for ferrimagnets (namely, alloy GdFeCo of rare-earth and transition metals) under the action of a laser pulse shorter than 100 fs [12]. The result of work [12], being typical of ferrimagnets only, turned out unexpected and rather unordinary. It was found that the reorientation effect has no relation to the light polarization. At the same time, it is associated only with an extremely short-term but strong specimen heating, when the maximum temperature exceeds the Curie point T_C [12] (see also a new approach to this problem based on the analysis of electronic processes running at the laser excitation of the metal [13]). The effect was detected for continuous films and microparticles [14], nanoparticles [15], and materials with and without the compensation point [14]. The microscopic origin of the reorientation effect is still not quite clear. It was only found that a change of the absolute values of sublattice magnetic moments $S_1 = |\mathbf{S}_1|$ and $S_2 = |\mathbf{S}_2|$ plays a substantial role in the effect formation [14, 16]. In other words, the purely longitudinal evolution of magnetic moments in the sublattices is essential for the effect description. The longitudinal dynamics of this kind is absent, in principle, in the case of the classical Landau–Lifshits equation [17], because, even if standard relaxation terms of the Landau–Lifshits–Gilbert type [17, 18] are taken into account, those equations preserve the absolute value of magnetization.

Earlier, one of the authors of this work showed that the longitudinal evolution of spins naturally arises while constructing the general scenario of the magnetization dynamics in ferro- [19] and antiferromagnets [20]. In this case, the direct influence of the exchange interaction on the spin evolution plays a specific role. Bearing in mind the symmetry of the exchange interaction, it cannot give rise to the variation of the total system spin. As a result, the contribution of this interaction to the standard transverse spin dynamics dominates only in the case where the standard relativistic relaxation is weak [21]. The phenomenological concept of exchange relaxation proposed in works [19, 20] turned out the most adequate tool for the description of the ultrafast spin dynamics, and it was used in works [16] to qualitatively describe experimental data. However, the absence of any progress in this approach with respect to ferrimagnets constrains the development of the quantitative description of longitudinal remagnetization effects.

This work is devoted to the derivation of the effective motion equations and the dissipative function for a two-sublattice ferrite, as well as to the analysis of various relaxation processes in this magnet on the basis of the obtained function. For ferrimagnets, various relaxation processes are of interest: the longitudinal relaxation (the relaxation of the magnetization, $\mathbf{M} = \mathbf{S}_1 + \mathbf{S}_2$, and antiferromagnetism, $\mathbf{L} = \mathbf{S}_1 - \mathbf{S}_2$, vector lengths) and the transverse one (it determines the damping of magnons in two branches). We demonstrate that, in contrast to the ferromagnet case, purely exchange processes of uniform relaxation described by a single universal constant Λ are possible. The fastest of them is the process of length relaxation for the antiferromagnetism vector. We show that this relaxation stems from the exchange interaction between the ferrite sublattices, and it is strengthened by the exchange interactions in the sublattices. The total magnetization of a ferrite relaxes much more slowly and, similarly to the case of a simple ferromagnet, is described by non-uniform exchange interactions and relativistic interactions. We also calculated the damping times for the optical and acoustic branches of spin waves in the ferrite. The damping decrement for the optical mode is determined by the same exchange constant Λ as the relaxation time of the antiferromagnetism vector length.

2. Quasiequilibrium Thermodynamic Potential of a Ferrite

Let us proceed from the following expressions for the quasiequilibrium thermodynamic potential of a two-

sublattice ferrite:

$$W = W_{e,u} + W_{e2} + W_a. \tag{2.1}$$

It includes the energy of the uniform exchange interaction

$$W_{e,u} = \frac{J_{11}}{4}\left(\mathbf{S}_1^2 - S_{01}^2\right)^2 + \frac{J_{22}}{4}\left(\mathbf{S}_2^2 - S_{02}^2\right)^2 + J_{12}\mathbf{S}_1\mathbf{S}_2,$$

the energy of the non-uniform exchange interaction

$$W_{e2} = \frac{\alpha_{11}}{2}\left(\nabla\mathbf{S}_1\right)^2 + \frac{\alpha_{22}}{2}\left(\nabla\mathbf{S}_2\right)^2,$$

and the energy of the uniaxial anisotropy

$$W_a = -\frac{1}{2}(K_{11}S_{1,z}^2 + K_{22}S_{2,z}^2).$$

The coefficients J_{11} and J_{22} determine the exchange interaction intensities in the first and second sublattices, respectively, and the parameter J_{12} describes the interaction between the sublattices. The uniaxial anisotropy with the constants of magnetic anisotropy $K_{11} > 0$ and $K_{22} > 0$ is assumed to take place in the sublattices, the easy axis is chosen to be directed along the z-axis, and α_{ii} are the constants of the non-uniform exchange interaction. In effect, the contribution to the thermodynamic potential associated with the exchange interaction in a sublattice is written down in the form of the Landau expansion, and the quantities S_{01} and S_{02} determine the equilibrium spin values at the given temperature, when the interaction between the sublattices is not taken into consideration. The relations between the constants that enter the energy expression are given by the inequalities $(J_{11}, J_{22}, J_{12}) \gg K_{11} \sim K_{22}$.

Knowing the quasiequilibrium thermodynamic potential, we can find the ground state of the ferrite and its corresponding magnetization. These quantities are determined by the formulas

$$\begin{aligned} &K_{11}\bar{S}_1 + J_{11}\bar{S}_1 X + \bar{S}_2 J_{12} = 0, \\ &K_{22}\bar{S}_2 + \bar{S}_1 J_{12} + \bar{S}_2 Y J_{22} = 0, \end{aligned} \tag{2.2}$$

where the following notation is introduced:

$$X \equiv S_{01}^2 - \bar{S}_1^2, Y \equiv S_{02}^2 - \bar{S}_2^2, \tag{2.3}$$

and the quantities $\bar{S}_1$ and $-\bar{S}_2$ ($\bar{S}_1 > 0$ and $\bar{S}_2 > 0$) stand for the magnitudes of sublattice magnetic moments in the ground state (since $J_{12} > 0$, the sublattice spins are antiparallel, and their averaged values $\bar{\mathbf{S}}_1$ and $\bar{\mathbf{S}}_2$ are directed "upward" and "downward", respectively). For the sake of definiteness, let us put $\bar{S}_1 > \bar{S}_2$.

3. Spin Dynamics and Dissipative Function of a Ferrite

In order to calculate the processes of spin-wave relaxation and damping, let us proceed from the Landau–Lifshits equations for spins in the sublattices,

$$\frac{\partial\mathbf{S}_1}{\partial t} = [\mathbf{S}_1, \mathbf{H}_1] + \mathbf{R}_1, \frac{\partial\mathbf{S}_2}{\partial t} = [\mathbf{S}_2, \mathbf{H}_2] + \mathbf{R}_2, \tag{3.1}$$

where

$$\mathbf{H}_1 = -\frac{\partial W}{\partial\mathbf{S}_1}, \mathbf{H}_2 = -\frac{\partial W}{\partial\mathbf{S}_2}$$

are effective fields in the sublattices, and $\mathbf{R}_1$ and $\mathbf{R}_2$ are dissipative terms. In the spirit of works [19, 20], the dissipative terms can be written down in terms of the dissipative function variations with respect to the corresponding effective field,

$$\mathbf{R}_1 = \frac{\partial q}{\partial\mathbf{H}_1}, \mathbf{R}_2 = \frac{\partial q}{\partial\mathbf{H}_2}. \tag{3.2}$$

Following the idea proposed by one of the authors (see work [19]), the dissipative function is constructed as a quadratic function of the effective magnetic fields and taking into account that it should be invariant with respect to the symmetry transformations of the ferrite. Those requirements allow us to determine the structure of every term associated with that or another interaction. It is easy to see that this structure looks like

$$q = q_u^e + q_u^r + q_{u,3}^r + q_{n,u}^e. \tag{3.3}$$

Here, the first term describes the contribution of the uniform exchange interaction,

$$2q_u^e = \mathbf{R}_1\mathbf{H}_1 + \mathbf{R}_2\mathbf{H}_2 = \Lambda(\mathbf{H}_1 - \mathbf{H}_2)^2, \tag{3.4}$$

which basically does not exist for ferromagnets. The meaning of other terms is the same as for ferromagnets, the terms $q_{u,z}^r$ and q_u^r are determined by the specific purely uniaxial or rhombic anisotropy,

$$\begin{aligned} &2q_{u,z}^r = \Lambda_z(H_{1,z}^2 + H_{2,z}^2); \\ &2q_u^r = \Lambda_1^r(H_{1,x}^2 + H_{1,y}^2) + \Lambda_2^r(H_{2,x}^2 + H_{2,y}^2), \end{aligned} \tag{3.5}$$

and the term $q_{n,u}^e$,

$$2q_{n,u}^e = \lambda_{11}^e(\nabla\mathbf{H}_1)^2 + \lambda_{22}^e(\nabla\mathbf{H}_2)^2,$$

describes the contribution of the non-uniform exchange. For a linear spin wave with the wave vector k, we have

$$2q^e_{n,u} = k^2(\lambda_1 \mathbf{H}_1^2 + \lambda_2 \mathbf{H}_2^2).$$

Here, we confined the consideration to the simplest formulas for the dissipative function. For instance, we did not write down invariants of the types $H_{1,x}H_{2,x}$, $H_{1,z}H_{2,z}$, and so on. Their account does not change final results, but makes the formulas for relativistic contributions to the damping much more cumbersome, whereas our main task is to analyze the uniform exchange contribution, which is unique for the ferrimagnet.

4. Conservation Law for Total Ferrite Magnetization

The exchange symmetry of the spin dynamics means that the quasiequilibrium potential of a ferrite does not change at uniform rotations of its magnetization and antiferromagnetism vectors. This type of symmetry brings about the conservation law for the total magnetization of the magnet. Using the equations of motion (3.1) under the condition $W_a = 0$, it is easy to get convinced that the differential form of the conservation law for the ferrite in the pure exchange approximation looks like

$$\frac{\partial(\mathbf{S}_1 + \mathbf{S}_2)}{\partial t} + \frac{\partial(\mathbf{\Pi}_k^{\rm dyn} + \mathbf{\Pi}_k^{\rm dis})}{\partial x_k} = 0, \tag{4.1}$$

where the vectors in the spin and coordinate spaces are transformed independently. The dynamic and dissipative parts of the magnetization flux are

$$\mathbf{\Pi}_k^{\rm dyn} = \alpha_{11}[\mathbf{S}_1, \frac{\partial \mathbf{S}_1}{\partial x_k}] + \alpha_{22}[\mathbf{S}_2, \frac{\partial \mathbf{S}_2}{\partial x_k}_2] \tag{4.2}$$

and

$$\mathbf{\Pi}_k^{\rm dis} = \lambda^e_{11}\frac{\partial \mathbf{H}_1}{\partial x_k} + \lambda^e_{22}\frac{\partial \mathbf{H}_2}{\partial x_k}, \tag{4.3}$$

respectively. It is important to emphasize that only the non-uniform exchange makes contribution to $\mathbf{\Pi}_k^{\rm dis}$, and this contribution is in fact the same as that for a ferromagnet. The uniform exchange dissipation characterized by the constant Λ and inherent only to a ferrimagnet does not change the form of $\mathbf{\Pi}_k^{\rm dis}$. In the case of uniaxial anisotropy, only the symmetry with respect to uniform rotations around the anisotropy axis takes place, and only the z-projection of the total moment, $S_{1,z} + S_{2,z}$, is preserved. The corresponding differential form of the conservation law for the ferrite looks like

$$\frac{\partial(S_{1,z} + S_{2,z})}{\partial t} + \frac{\partial(\Pi_k^{\rm dyn} + \Pi_k^{\rm dis})}{\partial x_k} = 0, \tag{4.4}$$

where the dynamic and dissipative parts of the magnetization flux are equal to $\Pi_k^{\rm dyn} = (\mathbf{e}_z, \mathbf{\Pi}_k^{\rm dyn})$ and $\Pi_k^{\rm dis} = (\mathbf{e}_z, \mathbf{\Pi}_k^{\rm dis})$, respectively, and $\mathbf{e}_z$ is the unit vector along the z-axis.

5. Linearized Equations of Motion

In order to calculate the spectra and the damping constants, let us proceed from the linearized Landau–Lifshits equations of motion making allowance for the dissipative terms (3.1)–(3.3). We write down the vectors $\mathbf{S}_1$ and $\mathbf{S}_2$ as follows: $\mathbf{S}_1 = \bar{S}_1\mathbf{e}_z + \mathbf{s}_1$ and $\mathbf{S}_2 = -\bar{S}_2\mathbf{e}_z + \mathbf{s}_2$. Let us first analyze the equations obtained by linearizing the equation of motion with respect to $\mathbf{s}_{1,2}$ and by neglecting the dissipation. It is convenient to consider the sum and the difference of the equations for the additives $\mathbf{s}_{1,2}$ in the form of their components along the axes. The sums of linearized equations for the components $\mathbf{s}_1$ and $\mathbf{s}_2$ obtained taking into account that the time dependence of small deviations is exponential and has the form of a simple wave with the wave vector $\mathbf{k}$, i.e. $s_{1,2} \propto \exp(\mathbf{kx} - i\omega t)$, look like

$$\begin{aligned}
&\text{(I)} \quad i\omega s_{1,x} - \bar{S}_1(K_{11} + k^2\alpha_{11})s_{1,y} + i\omega s_{2,x} \\
&+\bar{S}_2(K_{22} + k^2\alpha_{22})s_{2,y} = 0, \\
&\text{(II)} \quad \bar{S}_1(K_{11} + k^2\alpha_{11})s_{1,x} + i\omega s_{1,y} - \\
&-\bar{S}_2(K_{22} + k^2\alpha_{22})s_{2,x} + i\omega s_{2,y} = 0, \\
&\text{(III)} \quad i\omega(s_{1,z} + s_{2,z}) = 0.
\end{aligned} \tag{5.1}$$

Three more equations are obtained from difference of the equations for $\mathbf{s}_1$ and $\mathbf{s}_2$,

$$\begin{aligned}
&\text{(IV)} \quad i\omega s_{1,x} - \bar{S}_1(K_{11} + k^2\alpha_{11})s_{1,y} - i\omega s_{2,x} - \\
&-\bar{S}_2(K_{22} + k^2\alpha_{22})s_{2,y} = 0, \\
&\text{(V)} \quad \bar{S}_1(K_{11} + k^2\alpha_{11})s_{1,x} + i\omega s_{1,y} + \\
&+\bar{S}_2(K_{22} + k^2\alpha_{22})s_{2,x} - i\omega s_{2,y} = 0, \\
&\text{(VI)} \quad i\omega(s_{1,z} - s_{2,z}) = 0.
\end{aligned} \tag{5.2}$$

We now pay attention to that the exposed system of six equations can be split into three independent pairs of equations for the quantities $(s_{1,x} - is_{1,y}) = s_1^{(-)}$, $(s_{2,x} - is_{2,y}) = s_2^{(-)}$, $(s_{1,x} + is_{1,y}) = s_1^{(+)}$, $(s_{2,x} + is_{2,y}) = s_2^{(+)}$, $s_{1,z}$, and $s_{2,z}$. The first two pairs are obtained as linear combinations of Eqs. (5.1) and (5.2), namely,

$$\mathrm{IV} + i\mathrm{V} \to s_1^{(-)}(-\omega + \bar{S}_1 K_{11} + k^2 \bar{S}_1 \alpha_{11}) + s_2^{(-)}(\omega + \bar{S}_2 K_{22} + k^2 \bar{S}_2 \alpha_{22}) = 0, \tag{5.3a}$$

$$\mathrm{I} - i\mathrm{II} \to i s_1^{(-)}(\omega - \bar{S}_1 K_{11} - k^2 \bar{S}_1 \alpha_{11}) + s_2^{(-)}(\omega + \bar{S}_2 K_{22} + k^2 \bar{S}_2 \alpha_{22})) = 0, \tag{5.3b}$$

and

$$\mathrm{IV} - i\mathrm{V} \to s_1^{(+)}(\omega + \bar{S}_1 K_{11} + k^2 \bar{S}_1 \alpha_{11}) + s_2^{(+)}(-\omega + \bar{S}_2 K_{22} + k^2 \bar{S}_2 \alpha_{22}) = 0, \tag{5.4a}$$

$$\mathrm{I} + i\mathrm{II} = i s_1^{(+)}(\omega + \bar{S}_1 K_{11} + k^2 \bar{S}_1 \alpha_{11}) + s_2^{(+)}(\omega - \bar{S}_2 K_{22} - k^2 \bar{S}_2 \alpha_{22}) = 0. \tag{5.4b}$$

Equations III and VI for the pair $s_{1,z}$ and $s_{2,z}$ remain the same. This circumstance is not incidental but results from the crystal symmetry. If a uniaxial crystal is rotated by an angle φ around its symmetry axis, the quantities $s_1^{(+)}$ and $s_2^{(+)}$ are transformed according to the law $\left(s_1^{(+)}, s_2^{(+)}\right) \propto \exp(i\varphi)$, and the quantities $s_1^{(-)}$ and $s_2^{(-)}$ according to the law $\left(s_1^{(-)}, s_2^{(-)}\right) \propto \exp(-i\varphi)$, whereas the quantities $s_{1,z}$ and $s_{2,z}$ remain invariant. The same reasons are valid for the relaxation terms as well, because they were also constructed in accordance with the crystal symmetry.

6. Spin-Wave Spectra and Damping Constants

The linearized system of equations describes four types of characteristic motions in the spin system of the ferrimagnet. Two of them are purely dissipative; they govern the relaxation of the z-projections of the total spin and the antiferromagnetism vector. The two others have finite frequencies; they describe the frequencies of characteristic spin waves. We omit the stage of simple but cumbersome calculations and present only the results obtained for the spin-wave spectra and damping constants, and the relaxation times.

6.1. Acoustic spin waves

The frequency Ω_1 and the damping constant Γ_1 of an acoustic spin wave are determined by the formula

$$\omega_{\mathrm{acous}} = \Omega_1 - i\Gamma_1, \tag{6.1}$$

where

$$\Omega_1 = g\frac{(\bar{S}_1^2 K_{11} + \bar{S}_2^2 K_{22} + k^2(\bar{S}_1^2 \alpha_{11} + \bar{S}_2^2 \alpha_{22}))}{\bar{S}_1 - \bar{S}_2}, \quad \Gamma_1 = \frac{\Omega_1(k^2 \bar{S}_2 \lambda_m + k^2 \bar{S}_1 \lambda_s + \bar{S}_2 \Lambda_1^r + \bar{S}_2 \Lambda_2^r))}{2\Omega_2 \bar{S}_1 \bar{S}_2}. \tag{6.2}$$

6.2. Optical waves

For the optical waves, we obtain

$$\omega_{\mathrm{opt}} = \Omega_2 - i\Gamma_2, \tag{6.3}$$

where

$$\Omega_2 = g\frac{1}{(\bar{S}_1 - \bar{S}_2)}[\bar{S}_1 \bar{S}_2(K_{11} + k^2 \alpha_{11} + K_{22} + k^2 \alpha_{22}) + (\bar{S}_1 - \bar{S}_2)^2 J_{12}] \approx (\bar{S}_1 - \bar{S}_2) J_{12},$$

$$\Gamma_2 = \Lambda \frac{(\bar{S}_1 - \bar{S}_2)\Omega_2}{\bar{S}_1 \bar{S}_2} \approx \Lambda J_{12} \frac{(\bar{S}_1 - \bar{S}_2)^2}{\bar{S}_1 \bar{S}_2}, \tag{6.4}$$

6.3. Longitudinal relaxation

The damping of the components $M_z = S_{1,z} + S_{2,z}$ and $L_z = S_{1,z} - S_{2,z}$ is determined by the purely imaginary characteristic frequencies of the equations. It takes place according to the laws

$$L_z = \bar{S}_1 + \bar{S}_2 + \delta L(0) \exp(-\Gamma_L t), \quad M_z = \bar{S}_1 - \bar{S}_2 + \delta M(0) \exp(-\Gamma_M t), \tag{6.5}$$

where $\delta L(0)$ and $\delta M(0)$ are the initial deviations of the lengths of the antiferromagnetism and total spin vectors from their equilibrium values, which are assumed small. The damping constants are determined from the formulas

$$\Gamma_L = 2\Lambda(\bar{S}_1^2 J_{11} + \bar{S}_2^2 J_{22}) + \Lambda J_{12} \frac{(\bar{S}_1 - \bar{S}_2)^2}{\bar{S}_1 \bar{S}_2}, \quad \Gamma_M = \frac{4\bar{S}_1^2 \bar{S}_2^2 k^2 J_{11} J_{22} \lambda_m}{\bar{S}_1^2 J_{11} + \bar{S}_2^2 J_{22}}. \tag{6.6}$$

7. Discussion of the Results Obtained

From formulas (6.2), it follows that, in the isotropic approximation where $K_{11} = K_{22} = 0$ and $\Lambda_1^r = \Lambda_2^r = 0$, the frequencies and the damping constants acquire their well-known values, namely, $\Omega_1 \approx \alpha k^2$ and $\Gamma_1 \approx k^4$, obtained by Bloch [22] and Dyson [23] (see also work [24]) for a simple ferromagnet in the framework of microscopic theory; they also follow from the consistent phenomenological theory of exchange relaxation developed for ferromagnets [19]. The conclusion about an abnormally slow relaxation of acoustic waves is associated with the application of the isotropic approximation and the manifestation of the degenerate ground state in ferrites. One should recall that, in the isotropic state, the energies of all uniform states of a ferromagnet with an arbitrary orientation of the magnetization vector are identical. Just this circumstance manifests itself in the temporal behavior of the acoustic-spin-wave damping at $k \to 0$, i.e. $\tau \propto (1/k^4) \to \infty$. For the total spin relaxation, the result is also identical to that for a ferromagnet (see the microscopic analysis in [24] and the phenomenological consideration in [19]). The magnetization vector relaxation is stronger due to the exchange interaction (see Eq. (6.6)), but it is determined now by the constant of the non-uniform exchange interaction. Generally speaking, those two results are expectable; the current opinion consists in that the low-frequency dynamics for a ferrite far from the compensation point is not sensitive to the sublattice structure, being the same as that for the ferromagnet (a vicinity of the compensation point, where $\bar{S}_1 \to \bar{S}_2$, requires a special consideration [25], which goes beyond the scope of this work). Therefore, we do not discuss those quantities below.

The optical frequency is determined by the integral of the exchange interaction between the ferrite sublattices, J_{12}. We attract attention to that the damping of optical spin waves is large and determined by the uniform exchange relaxation constant Λ. This result corresponds to that obtained at microscopic calculations, in which the multiplier $(\bar{S}_1 - \bar{S}_2)^2$ and the temperature dependence $\Gamma \propto T^4$ are always obtained in the framework of various models [26, 27]. It is important to emphasize that the indicated features are inherent to considerably different systems, namely, to iron-yttrium ferrite garnet, in which two sublattices are formed by iron atoms and demonstrate a substantial exchange interaction [26], and to gadolinium ferrite garnet, where the exchange interaction between gadolinium atoms is negligibly low [27]. Therefore, we may expect that $\Lambda \propto T^4$, which is of interest to verify experimentally.

Hence, the analysis of formulas (6.2)–(6.6) for the relaxation constants testifies that the relaxation of the antiferromagnetism vector is the fastest process, the relaxation of optical spin waves is slower, the process of magnetization vector relaxation is even slower, and the relaxation of acoustic spin waves is the slowest process. The most interesting are the results of calculation for the relaxation of the antiferromagnetism vector **L**. From formulas (6.5) and (6.6), one can see that the relaxation of the vector **L** length is accelerated by the intra-sublattice exchange integrals J_{11} and J_{22}. On the other hand, it depends on the exchange relaxation constant Λ. Just this circumstance gives rise to a variation of the magnetization sign and the corresponding effects, which were observed in works [12, 14]. The system rapidly develops along the curve $S_1 + S_2 = \text{const}$ and finds itself in a strongly equilibrium state (see the corresponding qualitative analysis in work [16]). Of specific importance is the fact that both the damping of optical spin waves and the relaxation of the antiferromagnetism vector length L are governed by the same constant Λ. This allows one, firstly, to determine this constant from independent measurements and, secondly, to use the known methods of microscopic calculations for the magnon damping in order to estimate the relaxation time for the antiferromagnetism vector length l.

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ФЕНОМЕНОЛОГІЧНА ТЕОРІЯ
РЕЛАКСАЦІЇ У ДВОПІДҐРАТКОВОМУ ФЕРИТІ

Р е з ю м е

Побудовано дисипативну функцію двопідґраткового фериту. Обчислені часи релаксації акустичної та оптичної гілок спінових хвиль. Обчислено часи релаксації намагніченості і вектора антиферомагнетизму фериту. Показано, що найбільш швидким є процес релаксації вектора антиферомагнетизму. Час релаксації цієї величини визначається обмінною релаксаційною сталою і обмінно посилено за рахунок динаміки вектора антиферомагнетизму обмінними взаємодіями між атомами подґраток. Найбільш повільним процесом є процес релаксації намагніченості фериту. В обмінному наближенні час релаксації намагніченості прагне до нескінченності при зростанні довжини неоднорідностей намагніченості. Проведено зіставлення з експериментальними даними щодо явища релаксації в сплаві рідкісноземельних і перехідних металів GdFeCo.