EXCHANGE INTERACTION AND THE TEMPERATURE DEPENDENCE OF THE FARADAY EFFECT IN FERRIMAGNETS

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Submitted to JETP editor November 29, 1966

J. Exptl. Theoret. Phys. (U.S.S.R.) 52, 882-884 (April, 1967)

The temperature dependence of magnetic rotation of the plane of polarization α_F in $Tb_3Fe_5O_{12}$ is investigated at temperatures between 25 and 350°K. It is shown that at 110°K α_F changes sign in accordance with the temperature dependence of the nondiagonal component of the magnetic permeability tensor at infrared frequencies. The temperature dependence of the Tb^{3+} ion g-factor in terbium ferrite-garnets is determined.

In papers on the investigation of the Faraday effect in ferrite-garnets, it has been shown that in the infrared region of the spectrum they possess a considerable wavelength-independent rotation of the plane of polarization,[1,2] connected with the ferromagnetic and exchange resonances. In the case of ferrimagnets with two magnetic sublattices, the specific rotation of the plane of polarization is given by the expression

$$\alpha_F = \frac{\pi\sqrt{\epsilon}e}{mc^2}(g_1I_1 - g_2I_2). \quad (1)$$

Here, I_1, I_2 and g_1, g_2 are respectively the magnetic moments and spectroscopic splitting factors of the ions of the two magnetic sublattices, and ϵ is the dielectric constant of the ferrite. This expression follows from the nondiagonal component of the magnetic permeability tensor for the condition $\omega \gg \omega_{res}, \omega_{ex}$, where ω_{res} and ω_{ex} are respectively the frequencies of the ferromagnetic and exchange resonances, and its meaning is that the two sublattices make an independent contribution to the Faraday effect, with a sign corresponding to the orientation of the magnetic moment of the sublattice.[1] Since I_1, I_2, and ϵ can be found from magnetic and optical measurements, Eq. (1) can be used for the determination of the g-factor of the ions of the rare-earth sublattice. This method was proposed in[1] and used in[3] for the determination of the temperature dependence of the Dy^{3+} g-factor in dysprosium ferrite-garnet at temperatures between 77 and 290°K. It follows from Eq. (1), that besides the change of sign of α_F at the compensation point,[4] one should expect yet another change of sign of α_F at the realization of the condition

$$g_1(T)I_1(T) - g_2(T)I_2(T) = 0.$$

This second change of sign has not been found experimentally, although attempts to observe it have been made.

Krinchik and Tyutneva,[5] investigated the temperature dependence of α_F in $Dy_3Fe_5O_{12}$ and $Tb_3Fe_5O_{12}$ in the range from 77 to 290°K. As the temperature was lowered below the compensation point, the angle α_F diminished in absolute value, reached a minimum, and then again increased in absolute value without changing sign; this is difficult to explain within the above framework of the exchange mechanism for rotation of the plane of polarization at infrared frequencies.

For the proof of the correctness of this latter mechanism, we have investigated the Faraday effect in $Tb_3Fe_5O_{12}$ at temperatures between 25 and 350°K in a magnetic field of 8000 Oe, using an apparatus based on an IKS-21 spectrometer. A single-crystal sample of $Tb_3Fe_5O_{12}$ of thickness 0.15 cm was placed in the cold finger of a metal cryostat. Its temperature could be smoothly changed within the limits indicated above. The

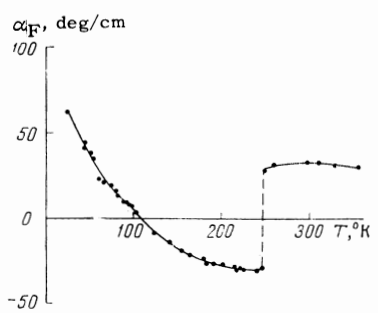

FIG. 1. Temperature dependence of the specific rotation of the plane of polarization in $Tb_3Fe_5O_{12}$ in the infrared region of the spectrum ($\lambda = 6.5\mu$).

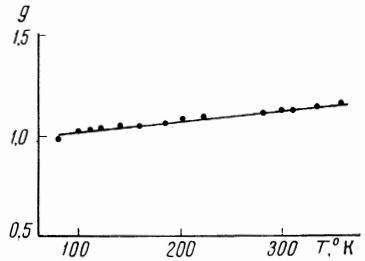

FIG. 2. Temperature dependence of the g-factor of the Tb^{3+} ion in $Tb_3Fe_5O_{12}$.

investigation was conducted in the wavelength band from 6 to 7.5 μ, since the transition $^7F_6 \rightarrow {}^7F_5$ in Tb^{3+} corresponds to a wavelength $\lambda = 5\ \mu$,[6] and the wavelength-independent rotation of the plane of polarization begins only at 6 μ.

The temperature dependence of α_F at $\lambda = 6.5\ \mu$ is depicted in Fig. 1. As the temperature is lowered from 350°K, the transition through the compensation point occurs, at which α_F changes sign; subsequently α_F decreases in absolute value, at 110°K changes sign once again, and after that grows until 25°K is reached. Qualitatively, the dependence $\alpha_F(T)$ obtained agrees with Eq. (1) if the Tb^{3+} g-factor is set equal to its free-ion value of 1.5. For quantitative agreement of the experimental and theoretical values of $\alpha_F(T)$, it is necessary to assume that the g-factor of the Tb^{3+} ion in the ferrite-garnet is less than 1.5 and monotonically decreases with temperature.

The difference between the $\alpha_F(T)$ obtained by us and that of[5], in which the second sign change at T = 110°K was not observed, was caused, apparently, by the fact that the latter investigation was carried out at $\lambda = 4\ \mu$, that is, where the contribution of the electronic transition of the Tb^{3+} ion to the rotation of the plane of polarization is still important. From the data of Fig. 1, the nondiagonal component of the tensor $[\mu]$ of $Tb_3Fe_5O_{12}$ can be obtained easily.

Figure 2 shows the temperature dependence g(T), obtained from $\alpha_F(T)$. The magnetizations of the Fe and Tb sublattices were calculated by us from the data of Harrison and Thompson[7]; $g_1 = 2.01$ was determined from the rotation of the plane of polarization in $Y_3Fe_5O_{12}$ under the assumption of identical g-factors for its two sublattices. The index of refraction of $Tb_3Fe_5O_{12}$ is taken to be 2.12, as it is for $Y_3Fe_5O_{12}$.[8] At temperatures lower than 80°K, a field of 8000 Oe is insufficient for magnetizing $Tb_3Fe_5O_{12}$ to saturation;[7] therefore we determined $g_2(T)$ in the interval from 80 to 350°K.

This method of determination of the rare-earth element g-factors differs in a favorable way from the determination of the g-factor from the ferromagnetic and exchange resonance absorptions, since the ferromagnetic resonance line is quite broad, and the exchange resonance is observed only at very low temperatures.[9] For the theoretical explanation of the dependence g(T) which was obtained, it is necessary to calculate exactly the splitting of the $^7F_6$ level in the intracrystalline and exchange fields of the iron-garnet. The beginning of such calculations was made in[10,11,6]. From the data of these papers, anisotropic α_F and g should be expected at helium temperatures.

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Translated by L. M. Matarrese
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