Anomaly of thermal expansion near the magnetic compensation temperature in rare earth ferrimagnets

S. A. Nikitin, D. Kim, A. K. Zvezdin, and A. F. Popkov

Moscow State University
(Submitted July 18, 1975)
Pis'ma Zh. Eksp. Teor. Fiz. **22**, No. 5, 297–300 (5 September 1975)

Anomalies of the thermal expansion were observed in the presence of a magnetic field near the magnetic-compensation temperature T_c in the compound $ErFe_3$ and in dysprosium iron garnet. It is shown that these anomalies can be attributed to a change in the magnetostriction contribution upon reorientation of the magnetic moments of the sublattices and formation of angle structures near T_c.

PACS numbers: 65.70.

Recently, many researches have become interested in induced angle structures in ferrimagnets near the magnetic-compensation temperature T_c.[1-7] So far, however, the thermal expansion in rare-earth alloys and iron garnets (RIG) near T_c has not been investigated, although a study of this property is very important for the determination of the character of the phase transition.

In this paper we study the linear thermal expansion of a polycrystalline sample of $ErFe_3$ prepared by the procedure of[8] and of the single-crystal RIG $Dy_3Fe_5O_{12}$ in magnetic fields up to 50 kOe near the magnetic-compensation points (T_c = 239 °K for $ErFe_3$ and 218 °K for $Dy_3Fe_5O_{12}$). The measurements were performed with wire-wound strain gauges in a magnetic field of a superconducting solenoid, in which an insert was placed to obtain temperatures in the range from 4.2 to 400 °K.

The thermal expansion of $ErFe_3$ is shown in Fig. 1, and that for $Dy_3Fe_5O_{12}$ (measured along the [111] axis) is shown in Fig. 2. We see that at $H=0$ the thermal expansion has no singularities whatever near T_c. However measurement of the thermal expansion of a sample in a magnetic field reveals near T_c anomalies that become more pronounced when the magnetic field is increased. We shall show below that the anomalies observed by us in the thermal expansion near T_c can be

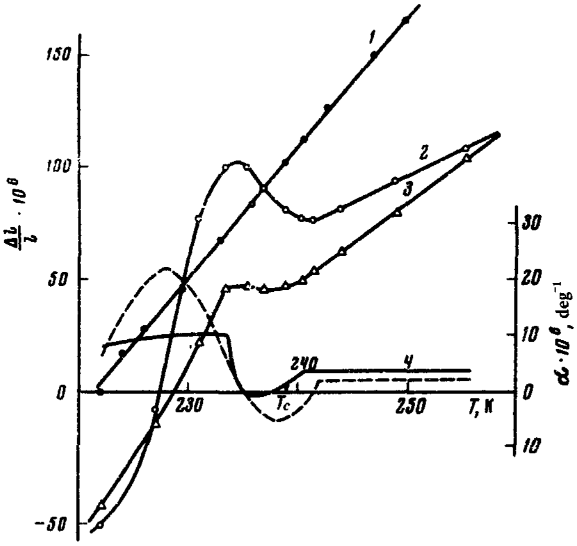

FIG. 1. Temperature dependence of the thermal expansion of the compound $ErFe_3$ near T_c at various values of the magnetic field (1—$H=0$; 2—$H=50$ kOe, 3—$H=15$ kOe) and of the thermal-expansion coefficient (5—$H=50$ kOe, 4—$H=15$ kOe).

attributed to a change of the magnetostriction contribution to the thermal expansion in the presence of a magnetic field. Consider the linear thermal expansion due to longitudinal magnetostriction. The magnetostriction change of the length in the direction of $\vec{\beta}=\{\beta_x, \beta_y, \beta_z\}$ in crystal with point symmetry group $\bar{3}m$ takes in the single-ion model the form

$$\Delta l/l = \Lambda_1(\gamma_z^2 - {}^1/_3) + \Lambda_2(\gamma_z^2 - {}^1/_3)(\beta_z^2 - {}^1/_3) + \Lambda_3[(\gamma_x^2 - \gamma_y^2) \times (\beta_x^2 - \beta_y^2)^2\, {}^1/_4 + \gamma_x\gamma_y\beta_x\beta_y] + \Lambda_4[(\beta_x^2 - \beta_y^2)\gamma_y\gamma_z\, {}^1/_2 + \gamma_x\gamma_y\beta_x\beta_y] + \Lambda_5[{}^1/_2(\gamma_x^2 - \gamma_y^2)\beta_y\beta_z + \gamma_x\gamma_y\beta_x\beta_z] + \Lambda_6[\gamma_y\gamma_z\beta_y\beta_z + \gamma_x\gamma_z\beta_x\beta_z], \quad (1)$$

where γ_i are the direction cosines of the magnetization of the rare-earth sublattice, and Λ_i are independent magnetoelastic constants.

The direction of the easy magnetization axis $\vec{\beta}=0, 0, 1$ the changes of the sample length are given by

$$\Delta l/l = \cos^2\theta(\Lambda_1 + {}^2/_3\Lambda_2) - {}^1/_3(\Lambda_1 + {}^2/_3\Lambda_2). \quad (2)$$

In the direction perpendicular to the easy axis we have

$$\Delta l/l = \cos^2\theta[-\Lambda_1 + {}^1/_3\Lambda_2 + {}^1/_4\Lambda_3] + {}^2/_3(\Lambda_1 - {}^1/_3\Lambda_2), \quad (3)$$

where $\cos\theta = (\mathbf{H}\cdot\mathbf{M}_1)/HM_1$.

We have not taken into account here the fact that when the anisotropy in the basal plane is neglected the rotation takes place in the (H, n_z) plane.

It is seen from the obtained formulas that the reorientation of the magnetization of the rare-earth sublattice $\cos\theta(H, T)$ near T_c leads to a strong change of the magnetostriction within the temperature interval of the reorientation. In this region we can approximately assume that $\cos\theta = \Delta T/\Delta T_{\text{reor}}$, where ΔT_{reor} is the half-width of this interval. The exact dependence of $\cos\theta$ on the temperature near T_c can be obtained from the condition of minimization of the free energy of a uniaxial two-sublattice ferrimagnet, as was done in[1].

In very strong fields, $H \gg H_{\text{cr}}$, the behavior of the magnetic structure is practically independent of the anisotropy. In the latter case we obtain from (1), after averaging over $\vec{\beta}$, that the magnetostriction contribution to the thermal expansion will be determined for a polycrystalline sample by the expression

$$\Delta l/l(H) = \Lambda^0 + \Lambda^1\cos^2\theta,$$

where

$$\Lambda^0 = {}^1/_3\Lambda_1 - {}^4/_{45}\Lambda_2 + {}^1/_{30}\Lambda_3 - {}^2/_5\Lambda_6,$$

$$\Lambda^1 = -{}^1/_3\Lambda_1 + {}^8/_{45}\Lambda_2 + {}^1/_{10}\Lambda_3 + {}^4/_{15}\Lambda_6, \quad (4)$$

$$\cos\theta = \frac{\lambda^2(M_1^2 - M_2^2) + H^2}{2\lambda H M_1},$$

M_1 and M_2 are the magnetizations of the sublattices of the rare earth and of the iron, respectively.

The measurement results enable us to estimate the uniaxial anisotropy from the temperature width of the anomalous region:

$$\frac{\Delta T}{T_c} = \frac{2K}{HT_c(\partial M_1/\partial T)(T_c)} + \frac{H}{\lambda M_1(T_c)}\left[\frac{M_1(T_c)}{T_c(\partial M_1/\partial T)(T_c)} - 1\right]. \quad (5)$$

Using the data of[9] we obtain from (5) the value $K = 4 \times 10^5$ erg/cm^3.

Thus, our measurements show that the large magnetostriction in the compound $ErFe_3$ and in $Dy_3Fe_5O_{12}$ leads to a noticeable anomaly in the temperature behavior of the linear thermal expansion near the magnetic-compensation point in the presence of a magnetic field. This can be attributed to reorientation of the magnetic moments of the sublattices and to the onset of noncollinear magnetic structures.

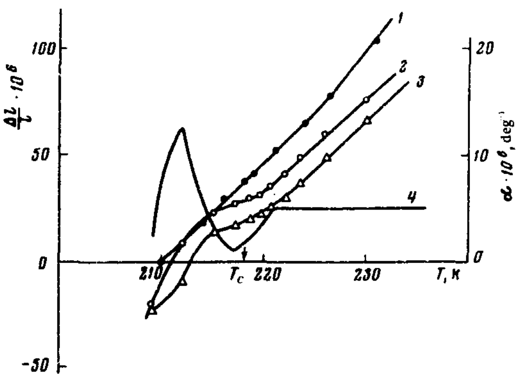

FIG. 2. Temperature dependence of the thermal expansion of single-crystal $Dy_3Fe_5O_{12}$ near T_c at various values of the magnetic field (1—$H=0$; 2—$H=50$ kOe; 3—$H=15$ kOe) and of the thermal-expansion coefficient in a 15-kOe magnetic field (curve 4).

In conclusion, the authors thank Professor K. P. Belov for a discussion of the results, B. V. Mill' and V. E. Kolesnichenko for supplying the samples for the investigation.

[1]A. K. Zvezdin and V. M. Matveev, Zh. Eksp. Teor. Fiz. **62**, 260 (1972) [Sov. Phys.-JETP **35**, 140 (1972)]; Isv. AN SSSR ser. fiz. **36**, 1441 (1972).
[2]K. P. Belov and S. A. Nikitin, Zh. Eksp. Teor. Fiz. **58**, 937 (1970) [Sov. Phys.-JETP **31**, 505 (1970)].
[3]K. P. Belov, Ferrity v sil'nykh magnitnykh polyakh (Ferrites in Strong Magnetic Fields), Nauka, 1972.
[4]A. E. Clark, B. F. Desavage, and E. R. Callen, J. Appl. Phys. **35**, 1928 (1964).
[5]R. Z. Levitin, B. K. Ponomarev, and Yu. F. Popov, Zh. Eksp. Teor. Fiz. **59**, 1952 (1970) [Sov. Phys.-JETP **32**, 1056 (1971)].
[6]A. M. Bisliev, A. K. Zvezdin, D. Kim, S. A. Nikitin, and A. F. Popkov, ZhETF Pis. Red. **17**, 484 (1973) [JETP Lett. **17**, 347 (1973)].
[7]D. A. Yablonskiĭ, Fiz. Tverd. Tela **14**, 2849 (1972) [Sov. Phys.-Solid State **14**, 2468 (1973)].
[8]K. P. Belov, S. A. Nikitin, A. M. Bisliev, E. M. Savitskiĭ, V. F. Terekhova, and V. E. Kolesnichenko, Zh. Eksp. Teor. Fiz. **64**, 2154 (1973) [Sov. Phys.-JETP **37**, 1086 (1973)].
[9]S. A. Nikitin and A. M. Bisliev, Fiz. Tverd. Tela **15**, 3681 (1973) [Sov. Phys.-Solid State **15**, 2451 (1974)].