

## FEATURES OF THE TEMPERATURE DEPENDENCE OF THE MAGNETIZATION OF THULIUM ORTHOFERRITE

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The weak ferromagnetism of orthoferrites of rare-earth elements (general formula  $RFeO_3$ , where R is the rare-earth element ion) is due to the non-collinear arrangement of the magnetic moments of the iron sublattices [1]. The rare-earth ions in the orthoferrites are in a magnetically-disordered state and can be ordered only at very low temperatures. An exchange interaction should exist between the iron and the rare-earth ions and induce an additional magnetic moment in the system of paramagnetic rare-earth ions, so that the total magnetic moment should be equal to

$$M = M_s + I_{AB} \chi_p$$

where  $M_s$  is the resultant spontaneous moment of the iron sublattices,  $I_{AB}$  is the exchange-interaction parameter, and  $\chi_p$  is the susceptibility of the rare-earth ions [2].

Because of the strong temperature dependence, the second term, which represents the induced magnetic moment in the system of rare-earth ions, may be larger at low temperatures than the resultant spontaneous magnetization of the iron sublattices, and the temperature dependence of the magnetization of the orthoferrite should have a compensation point if the exchange-interaction parameter  $I_{AB}$  is negative.

We observed a similar anomalous temperature dependence in the magnetization of thulium orthoferrite. When the temperature was reduced to 90°K the magnetic moment was reoriented from the c-axis to the a-axis of the crystal, in accord with the data of [3].

Below 90°K, the spontaneous magnetic moment of the single-crystal thulium orthoferrite is rigidly oriented along the a-axis of the rhombic crystal, and the rotary moment for the (001) plane can be expressed by the relation:

$$M(001) = \pm \sigma_0 H \sin \varphi - \frac{\chi_a - \chi_b}{2} H^2 \sin 2\varphi \quad (1)$$

where  $\varphi$  is the angle between the axis and the field,  $\sigma_0$  the spontaneous magnetization, and  $\chi_a$  and  $\chi_b$  the susceptibilities along the a and b axes of the crystal. The  $\pm$  sign in front of the first term corresponds to a discontinuity in the rotary moment when the magnetization of the sample is reversed along the a axis at  $\varphi = 90^\circ$ . Figure 1 shows plots of the rotary moments in the (001) plane of single-crystal thulium orthoferrite at temperatures 78 to 4.2°K. Using these curves we can obtain, from the rotary moment at  $\varphi = 90^\circ$ , the values of the magnetization at different temperatures. The temperature dependence thus obtained for the magnetization is

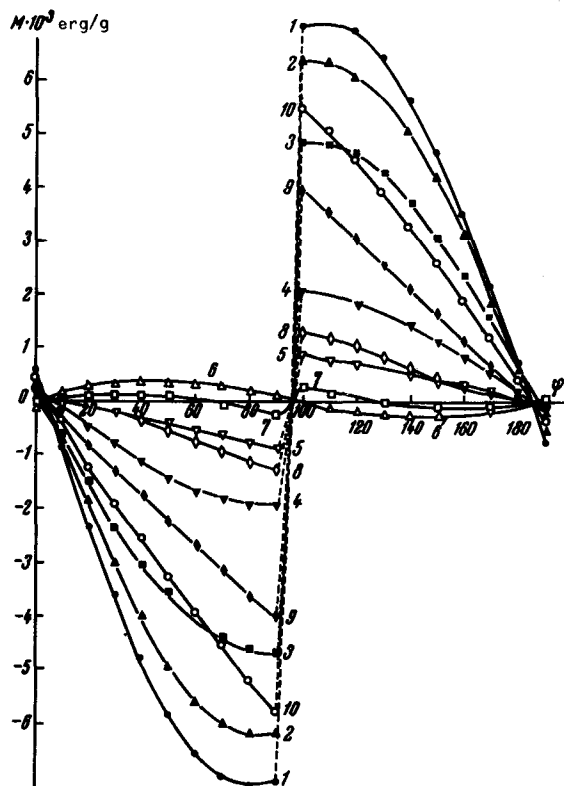


Fig. 1. Rotary moment of single-crystal thulium orthoferrite in the (001) plane, plotted in a field of 6.25 kOe at the following temperatures: 1 - 78, 2 - 58, 3 - 39.5, 4 - 26.5, 5 - 22.6, 6 - 18, 7 - 17, 8 - 14, 9 - 8, 10 - 4.2°K.

tion along the a-axis again begins to increase.

The vanishing of the spontaneous magnetization is obviously the result of compensation of the magnetic moments of the iron and thulium ions, which, as noted above, should be observed if the exchange interaction between these ions is negative. An analogous phenomenon was apparently observed by the authors earlier for samarium orthoferrite at 4.2°K [4], but it was difficult there to present an unambiguous explanation of the observed phenomenon, since no measurements were made below the compensation point.

As is well known, magnetic-compensation points are observed for the majority of rare-earth ferrites with garnet structure. As follows from our measurements, these are also possessed by some orthoferrites of rare-earth elements.

- [1] Bozorth, Kramer, and Remeika, *Phys. Rev. Lett.* 1, 3 (1958).
- [2] E. A. Turov, *FMM* 11, 321 (1961).
- [3] Kuroda, Miyadai, Naemura, Niizeki, and Takata, *Phys. Rev.* 122, 446 (1961).

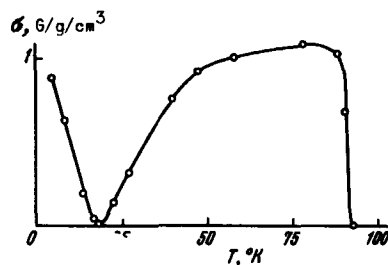


Fig. 2. Temperature dependence of the spontaneous magnetization of single-crystal thulium orthoferrite along the a-axis.

shown in Fig. 2. At 92°K the spontaneous magnetization along the a-axis is zero, for at this temperature the magnetic moment is still oriented along the c-axis of the crystal.

After a slight decrease in the temperature (~2°), the magnetization along the a-axis increases rapidly, reaching a value 1 G/g/cm<sup>3</sup>, owing to the reorientation of the magnetic moment from the c-axis to the a-axis. With further drop in temperature, the magnetization decreases smoothly, vanishing at 18°K. The plot of the rotary moment at this temperature (Fig. 1) is a sinusoid and no discontinuity corresponding to spontaneous magnetization is seen at  $\phi = 90^\circ$ . Below 18°K, the spontaneous magnetiza-

[4] Belov, Kadomtseva, Ovchinnikova, and Timofeeva, FMM 19, 778 (1965).

# ELECTROMAGNETIC SPLITTING OF THE MASSES OF THE 70-PLET IN THE SU(6) SYMMETRY SCHEME

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The classification of new baryon resonances in the 70-plet of the SU(6) symmetry group, and also their mass ratios, were discussed in several papers [1-3]. The relations between the magnetic moments for this multiplet were found in [4,5]. In this paper we consider the electromagnetic mass splitting for this multiplet.

Following Kuo and Yao [6], we assume that the electromagnetic mass splitting is a second-order effect in the electromagnetic interaction, and that the corresponding Hamiltonian is of the form

$$H_{em} = aQQ + b\vec{M}\vec{M} \quad (1)$$

where  $Q$  and  $\vec{M}$  transform like the charge and magnetic-moment operators, respectively:

$$Q = A_1^1 + A_4^4$$

$$\vec{M} = Q\vec{\sigma}$$

We assume at the same time that the magnetic moments of all the possible quarks of which the 70-plet can be made up are the same.

The states of the 70-plet are described by a mixed-symmetry tensor  $\Psi_{[AB]C}$  [7]

$$\Psi_{[AB]C} = \frac{A}{\sqrt{6}} \epsilon_{\alpha\beta\gamma} X_{(ij)k} + \frac{\sqrt{2}}{3} [2\Psi_{[\alpha\beta]\gamma} X_{(ij)k} - \Psi_{[\beta\gamma]\alpha} X_{(jk)i} - \Psi_{[\gamma\alpha]\beta} X_{(ki)j}]$$

$$+ \Phi_{(\alpha\beta\gamma)} X_{[ij]k} + \xi_{[\alpha\beta]\gamma} X_{(ijk)} \quad (2)$$

where  $A \equiv (\alpha i)$ ,  $B \equiv (\beta j)$ , and  $C \equiv (\gamma k)$ ;  $\alpha$ ,  $\beta$ , and  $\gamma$  are unitary indices;  $i$ ,  $j$ , and  $k$  are spin indices. Expression (2) corresponds to the expansion of the irreducible representation of the SU(6) 70 group into the following irreducible representations of the subgroup SU(3)  $\otimes$  SU(2):

$$\underline{70} = (1,2) + (8,2) + (10,2) + (8,4)$$

where <sup>1)</sup>

$$(1,2) : \Lambda^*$$

$$(8,2) : \tilde{N}, \tilde{\Sigma}, \tilde{\Lambda}, \tilde{\Xi}$$

$$(10,2) : \tilde{N}^*, \tilde{Y}_1^*, \tilde{\Xi}^*, \tilde{\Omega}$$

$$(8,4) : N_\gamma, \Sigma_\gamma, \Lambda_\gamma, \Xi_\gamma$$

The Hamiltonian (1) leads to the following general expression for the matrix element

$$\langle 70 | H_{em} | 70 \rangle = \sum_{Tr} a_i \bar{\Psi} Q Q \Psi + \sum_{Tr} b_i \bar{\Psi} \vec{M} \vec{M} \Psi \quad (3)$$