EFFECT OF UNIAXIAL AND HYDROSTATIC PRESSURES ON THE SPIN-REORIENTATION TEMPERATURE IN THULIUM ORTHOFERRITE

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The effect of uniaxial and hydrostatic pressures on the spin-reorientation temperature has been studied in a monocrystal of thulium orthoferrite. It was found that a uniaxial pressure $p_z = 1.5$ kbar, applied along the c axis of the rhombic crystal, shifts the reorientation temperature by $\Delta T \approx 10°K$. When a hydrostatic pressure (~1.7 kbar) is applied to a monocrystal of thulium orthoferrite, the spin-reorientation temperature is shifted only slightly ($\Delta T \approx 1°K$). The observed results are discussed within the framework of a thermodynamic treatment.

IT follows from thermodynamic considerations that an external uniaxial pressure should shift the spin-reorientation temperature in rare-earth orthoferrites. It was noted in [1] that upon application of external elastic stresses along the c axis of a rhombic crystal, the total energy of rare-earth orthoferrites, in the region of spin reorientation in the (ac)-plane, can be written in the form

$$F = F_0 + K_1 \sin^2\theta + K_2 \sin^4\theta + L_z\xi_z \sin^2\theta + {}^1/_2 E_z\xi_z^2 + \xi_z p_z, \quad (1)$$

where F_0 is the part of the energy that is independent of the orientation of the antiferromagnetism vector and of the deformation, θ is the angle between the direction of the weakly ferromagnetic moment and the c axis of the crystal, K_1 and K_2 are the first and second magnetic-anisotropy constants,[1)] L_z is the magnetoelastic energy constant, E_z is Young's modulus, p_z is the external uniaxial stress, and ξ_z is the strain along the c axis of the rhombic crystal. From the condition for a minimum of the energy with respect to ξ_z and θ, with allowance for the fact that near the spin-reorientation temperature $K_1 = a(T - T_2)$—where $a = -2K_2/(T_1 - T_2)$ (T_1 and T_2 are the temperatures at the beginning and end of the reorientation process)[2]—one can find the dependence of the shift of reorientation temperature on the amount of the external uniaxial pressure along the c axis:

$$\Delta T = L_z p_z / aE_z. \quad (2)$$

We conducted experiments for the direct determination of the amount of shift of the spin-reorientation temperature under the influence of a uniaxial pressure, which was produced by mechanical compression of the specimen by a special plug screwed into the case of a beryllium-bronze bomb. The previously oriented crystal was fastened inside the bomb, and the bomb was suspended on tension wires from the quartz fiber of a torsion balance. Figure 1 shows the temperature dependence of the spontaneous magnetization of the monocrystal of thulium orthoferrite along the a axis of the crystal, determined from torque curves taken in the (ac)-plane, without pressure and with uniaxial pressure $p_z \approx 1.5$ kbar along the c axis of the crystal. As is seen from the figure, this pressure shifts the temperature of the center of the reorientation range by an amount ~10° (as center of the reorientation range, that temperature is taken for which the most rapid decrease of magnetization is observed). We also determined the amount of shift of the spin-reorientation temperature by formula (2); we determined experimentally the values of the elastic and magnetoelastic moduli and of the coefficient a. For the monocrystal of thulium orthoferrite

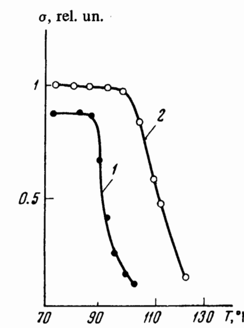

FIG. 1. Temperature dependence of the spontaneous magnetization along the a axis of a monocrystal of thulium orthoferrite: 1, without pressure; 2, under uniaxial pressure 1.5 kbar.

$$L_z = (5 \pm 0.5) \cdot 10^7 \text{ erg/cm}^3;$$
$$E_z = (1.9 \pm 0.2) \cdot 10^{12} \text{ dyn/cm}^2;$$
$$a = 5 \cdot 10^3 \text{ erg/cm}^3 \text{ deg}$$

and at pressure $p_z \approx 1.5$ kbar, the amount of shift of the reorientation temperature calculated by formula (2) is $\Delta T \approx 10°$, which agrees well with the shift observed experimentally.

It is seen from Fig. 1 that the spontaneous magnetization (at $T < T_1$) changes slightly under uniaxial compression; that is, the Dzyaloshinskiĭ constant must depend on pressure. The part of the magnetoelastic energy that corresponds to this is included in (1) in the term $L_z \xi_z \sin^2\theta$; and besides this, one should add a term of the form $L'_z \xi_z \sin^4\theta$. Allowance for the latter term leads to a change of the reorientation interval $(T_2 - T_1)$ with pressure; but according to Fig. 1, the corresponding effect is small and lies within the limits of experimental accuracy.

The effect of hydrostatic pressure on the spin-reori-

1)The anisotropy constants K_1 and K_2 take account also of the anisotropic part of the energy due to the Dzyaloshinskiĭ energy [2].

entation process was considered in [3]. A thermodynamic formula was obtained for the critical pressure p_c that produces a reorientation of the spins:

$$p_c = \frac{b_3 - b_1}{2\Delta^{-1}[(s_1' + s_2' + s_3') - (s_1 + s_2 + s_3)]}, \qquad (3)$$

where $(b_3 - b_1)/2 = K_1$, and where $\Delta^{-1}(s_i' - s_i)$ $(i = 1, 2, 3)$ is the deformation along the corresponding axis of the crystal upon reorientation of the spins. On allowing for the temperature dependence of the first anisotropy constant near the spin-reorientation range, $K_1 = a(T - T_2)$,[2] we obtain an expression for the shift of the reorientation temperature under the influence of hydrostatic pressure:

$$\Delta T = \Delta^{-1}[(s_1' + s_2' + s_3') - (s_1 + s_2 + s_3)]p_c/a. \qquad (4)$$

The value of $\Delta^{-1}(s_i' - s_i)$ can be determined from measurement of the magnetostriction and of the jump in Young's modulus when the antiferromagnetism of the iron-ion spins is turned over by a magnetic field. It is easy to see that when a uniaxial pressure is considered, formula (4) goes over to formula (2), since

$$\Delta^{-1}(s_i' - s_i) = L_i / E_i. \qquad (5)$$

Measurements of the magnetostriction when the spins are turned over have shown that the magnetostriction along the a and b axes of the crystal is negative, along the c axis positive; hence it follows, according to formula (4), that hydrostatic pressure should show a smaller effect than uniaxial on the reorientation temperature. We made an attempt to measure the shift of the reorientation temperature under the influence of hydrostatic pressure, which was produced by freezing of water inside a special bomb suspended from the quartz fiber of a torsion balance. From the torque curves taken at various temperatures, the temperature dependence of the spontaneous magnetization was determined without pressure and under application of hydrostatic pressure (Fig. 2).

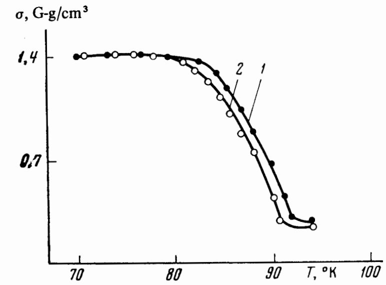

FIG. 2. Temperature dependence of the spontaneous magnetization of thulium orthoferrite along the a axis of the rhombic crystal: 1, without pressure; 2, under hydrostatic pressure 1.7 kbar.

It is seen from Fig. 2 that at pressure ~1.7 kbar, the reorientation temperature changes only slightly ($\Delta T \approx 1°$); the sign of the temperature shift is opposite to that observed under uniaxial pressure. The small value of the shift of reorientation temperature under hydrostatic pressure in thulium orthoferrite is explained by the small value of the summed deformation on spontaneous reorientation of the spins, $\sum \Delta^{-1}(s_i' - s_i)$. In fact, on substituting into formula (5) the values of the magnetoelastic constants determined from the jumps of Young's modulus along the various crystallographic axes,[1] and on allowing for the small difference in the value of Young's modulus along the a, b, and c axes of the crystal, we get

$$\sum_{i=1,2,3} \frac{1}{\Delta}(s_i' - s_i) = \sum_i \frac{L_i}{E_i} =$$

$$= \frac{10^7[(-2,8 \pm 0.3) + (-2.2 \pm 0,2) + (5 \pm 0.5)]}{1.9 \cdot 10^{12}} = (0 \pm 0,5) \cdot 10^{-5},$$

that is, under hydrostatic pressure the sign of the shift of reorientation temperature can be different from that under uniaxial pressure, and the amount of the shift should be of a smaller order.

In closing, we express our thanks to V. A. Timofeev, who grew the monocrystals of thulium orthoferrite used in this investigation.

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238