TRANSITIONS DUE TO SPIN REORIENTATION IN A $Ho_{0.5}Dy_{0.5}FeO_3$ SINGLE CRYSTAL

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The magnetic and elastic properties of new monocrystals of $Ho_{0.5}Dy_{0.5}FeO_3$, grown from solution in a lead-compound melt and by the zone-fusion method, have been investigated. It was discovered that in this orthoferrite, in the low-temperature range, there are two transitions (two Morin points) from the weakly ferromagnetic to the antiferromagnetic state, caused by a double reorientation of the iron-iron spins ($G_xF_z \rightarrow G_y \rightarrow G_zF_x$); the transition $G_zF_x \rightarrow G_y$ is observed for the first time in orthoferrites. It is shown that the two transitions are of significantly different characters.

ONE of the most remarkable peculiarities of the magnetic behavior of rare-earth orthoferrites is the occurrence of transitions caused by the spontaneous reorientation of the spins of the iron ions. Hitherto, two types of such transitions have been known: a transition from one weakly ferromagnetic state to another, with change of the spin orientation from the a to the c axis of the rhombic crystal ($G_xF_z \rightarrow G_zF_x$), observed in a whole series of rare-earth orthoferrites (for example, in samarium, holmium, and thulium orthoferrites[1,2]); and a transition from a weakly ferromagnetic to a purely antiferromagnetic state, accompanied by reorientation of the spins from the a axis to the b axis of the crystal ($G_xF_z \rightarrow G_y$), observed for example in dysprosium orthoferrite[1,3,4].

We have succeeded in synthesizing and investigating new monocrystals of the mixed composition $Ho_{0.5}Dy_{0.5}FeO_3$, in which for the first time two transitions due to spin reorientation have been observed: from a weakly ferromagnetic to an antiferromagnetic state ($G_xF_z \rightarrow G_y$) and from the antiferromagnetic to a weakly ferromagnetic state ($G_y \rightarrow G_zF_x$); a transition of the second type has never before been observed in orthoferrites.

The $Ho_{0.5}Dy_{0.5}FeO_3$ monocrystals were grown by two methods: spontaneous crystallization from solution in a lead-compound melt, and the method of crucibleless zone fusion.

On the monocrystals obtained, measurements of the torque curves were made in various crystallographic planes, and the temperature dependence of Young's modulus and of sound absorption was measured in the temperature range from 78 to 2°K. The measurements of the torque curves were made on a magnetic torsion balance with an autocompensator; Young's modulus was measured by the composite oscillator method at frequency 200 kHz. From Torque curves taken at various temperatures, the temperature dependence of the spontaneous magnetization was determined (Fig. 1). It is evident from Fig. 1 that at high temperatures, the magnetic moment is oriented along the c axis of the rhombic crystal; this corresponds to orientation of the antiferromagnetism vector of the iron ions along the a axis of the crystal (magnetic structure G_xF_z). On lowering of the temperature below 47°K, there was observed in the crystal under investigation a disappearance of the weak ferromagnetism and a transition to an antiferromagnetic state; this is possible, as follows from a consideration of the magnetic symmetry[5], by reorientation of the antiferromagnetism vector along the b axis of the rhombic crystal (the transition $G_xF_z \rightarrow G_y$). On further lowering of the temperature, the crystal remained antiferromagnetic down to 25°K, where a new transition was observed from the antiferromagnetic to the weakly ferromagnetic state with magnetic moment oriented along the a axis of the rhombic crystal (the transition $G_y \rightarrow G_zF_x$).

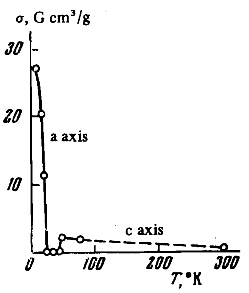

FIG. 1

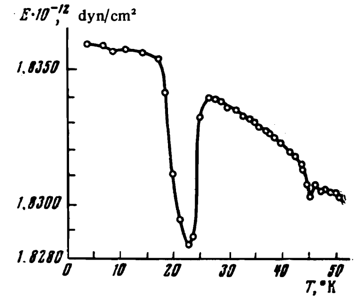

FIG. 2

FIG. 1. Temperature dependence of the spontaneous magnetization of a $Ho_{0.5}Dy_{0.5}FeO_3$ monocrystal.

FIG. 2. Temperature dependence of Young's modulus of a $Ho_{0.5}Dy_{0.5}FeO_3$ monocrystal, measured along the b axis of the rhombic crystal.

In analyzing the reasons that lead to the occurrence of the second transition, it must be noted that the magnetic properties of a $Ho_{0.5}Dy_{0.5}FeO_3$ monocrystal are strongly affected by the exchange interaction between the spins of the iron ions and of the rare-earth elements. Under the influence of the exchange interaction there apparently occurs an ordering of the holmium ions, in the liquid-helium temperature range, according to the model C_yF_x, similar to that observed in pure holmium orthoferrite[5-8]; evidence for this is the increase of the magnetic moment along the z axis to a value of 27 G cm³/g (about 3 μ_B per holmium ion). On the other hand, ordering of the holmium ions according to the model C_yF_x in the presence of exchange interaction promotes—as follows from consideration of

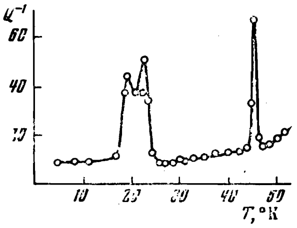

FIG. 3. Temperature dependence of sound damping in a $Ho_{0.5}Dy_{0.5}FeO_3$ moncrystal, measured along the b axis of the rhombic crystal.

the magnetic symmetry[5]—reorientation of the spins of the iron ions along the c axis of the crystal, with magnetic moment along the a axis (G_XF_Z); this also was observed in our experiments.

The occurrence of two transitions caused by reorientation of the spins in a $Ho_{0.5}Dy_{0.5}FeO_3$ monocrystal was further corroborated by our measurement of the temperature dependence of Young's modulus and of the damping: anomalies were observed at the reorientation temperatures (Figs. 2 and 3).

Anomalies in the temperature dependence of Young's modulus on reorientation of the spins were observed by us earlier in the transition $G_XF_Z \rightarrow G_ZF_X$. This transition was accomplished by a smooth rotation of the spins; Young's modulus showed jumps at two temperatures, at the beginning and at the end of the reorientation process, corresponding to two phase transitions of the second kind[9].

As is seen from Fig. 2, the anomalies of Young's modulus on reorientation of the spins near 45 and in the neighborhood of 21°K differ significantly from each other. In the low-temperature transition $G_ZF_X \rightarrow G_Y$, there are two jumps in Young's modulus, at temperatures $T_1 = 18.5$°K and $T_2 = 24.2$°K, similar to what was observed for the transition $G_XF_Z \rightarrow G_ZF_X$; this is evidence of a gradual rotation of the spins in the reorientation process. The significant decrease of Young's modulus in the temperature range of spin reorientation is due to the fact that in this temperature interval, the spins rotate spontaneously with change of temperature, and this facilitates their rotation by an external stress and makes the crystal in effect less stiff. A qualitatively different anomaly of Young's modulus occurs near 45°K at the transition $G_XF_Z \rightarrow G_Y$. Here the temperature dependence of Young's modulus does not show two jumps of the modulus, but there is only a small negative pip on reorientation of the spins; this gives reason to suppose that the reorientation process occurs in this case not by a smooth rotation of the spins, but by a jump—that is, application of external stresses does not promote a smooth rotation of the spins, but changes the ratio between the phases with spin orientations along the a axis (G_XF_Z) and along the b axis (G_Y) of the rhombic crystal. The slight difference in Young's modulus to the left and to the right of the transition temperature is evidently due to the fact that the stiffness of the crystal is here slightly different in the weakly ferromagnetic and in the antiferromagnetic states.

In the temperature dependence of the sound absorption (Fig. 3), maxima of the damping were observed at temperatures near 21 and 46°K; these are evidently due to irreversible energy losses in the spin-reorientation process. In the low-temperature transition, a double maximum of the damping was obtained; this indicates an increase of the damping at the beginning and at the end of the reorientation process.

It should be mentioned that transitions from the antiferromagnetic to the weakly ferromagnetic state in orthoferrites have hitherto been little studied, but that a transition of the type $G_ZF_X \rightarrow G_Y$ was first observed by us in orthoferrites. The compound $Ho_{0.5}Dy_{0.5}FeO_3$ discovered by us is so far the only orthoferrite that exhibits two transitions, different in character, from the weakly ferromagnetic to the antiferromagnetic state, and therefore it is an extremely convenient, unique material for clarification of the nature of such transitions.

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234