# *REORIENTATION OF THE ANTIFERROMAGNETIC VECTOR OF SOME RARE-EARTH ORTHOFERRITES IN STRONG MAGNETIC FIELDS*

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Switching of the antiferromagnetic iron sublattices by a magnetic field applied along the antiferromagnetic axis was observed for some single crystals of rare-earth orthoferrites. The values of the threshold and anisotropy fields of europium and yttrium orthoferrites varied little with temperature in the range 300–78°K. A strong temperature dependence of the anisotropy constant was observed for those orthoferrites which exhibited a spontaneous spin reorientation at some definite temperature.

It is known that rare-earth orthoferrites exhibit a weak ferromagnetism due to a noncollinear alignment of the spins of the antiferromagnetic iron sublattices.[1,2] When a sufficiently strong magnetic field ($\sim 10^5$ Oe) is applied along the antiferromagnetic axis of these compounds, switching of the antiferromagnetic iron sublattices, accompanied by reorientation of the spontaneous magnetic moment, should be observed.[2] In weakly ferromagnetic orthoferrites, the reorientation of antiferromagnetic sublattices in a magnetic field should be gradual,[3,4] as observed experimentally for samarium orthoferrite.[3] According to the results reported in[3], the value of the threshold field, at which the antiferromagnetic vector is switched from the direction parallel to the external magnetic field to the perpendicular direction, amounts to ~60 kOe for samarium orthoferrite at room temperature.

We measured the threshold fields of the orthoferrites $SmFeO_3$, $EuFeO_3$, $YFeO_3$, and of mixed orthoferrites of the system $Eu_xSm_{1-x}FeO_3$. The value of the threshold field was determined by measuring the dependence of the torque on the intensity of the field applied along the antiferromagnetic axis. These measurements were carried out using magnetic field pulses of up to 120 kOe intensity and of ~10 msec duration.

Figure 1 shows the dependences of the torque on the angle between the direction of the external magnetic field and the a axis of an $SmFeO_3$ crystal, recorded in the ac plane at room temperature and at 78°K. At room temperature, the torque curves recorded in fields of 25 and 50 kOe, i.e., below the threshold, had discontinuities when the field was oriented along the antiferromagnetic axis (c axis), due to the tendency of the crystal to rotate so that the transverse spontaneous magnetic moment would be directed along the field. The discontinuity for a rigid orientation of the magnetic moment along the a axis of the crystal was $\sigma_0 H$, where $\sigma_0$ is the spontaneous magnetic moment.

In stronger fields, comparable with the threshold value, the discontinuities in the torque curves disappeared because, in such fields, the magnetic moment began to rotate with the external field. The value of the threshold field, determined from the point of steepest fall in the dependence of the torque on the field applied along the antiferromagnetic axis, was ~60 kOe for $SmFeO_3$. The torque curves, recorded as a function of the angle at 78°K, exhibited discontinuities right up to 120 kOe, which indicated that the magnetic moment was not rotated by these fields. Thus, at 78°K the threshold field of $SmFeO_3$ exceeded 120 kOe, i.e., it exhibited a strong temperature dependence.

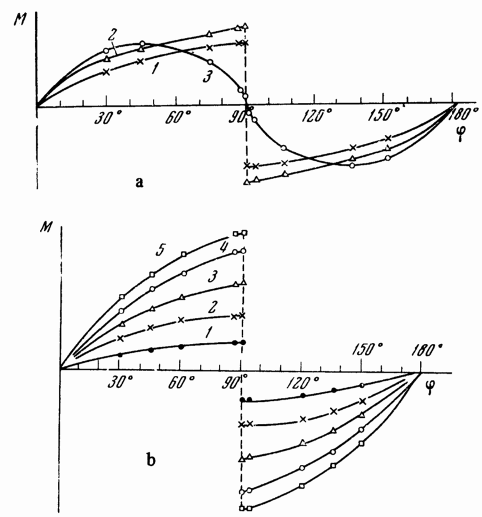


FIG. 1. Torque curves (in relative units) of an $SmFeO_3$ single crystal, recorded in the ac plane: a) at room temperature, T = 300°K; b) at 78°K ($\varphi$ is the angle between the c axis and the magnetic field direction). These curves were obtained in magnetic fields (kOe): 1) 25; 2) 50; 3) 75; 4) 100; 5) 120.

The switching of the antiferromagnetic sublattices by a magnetic field was observed also for $EuFeO_3$. Figure 2 shows the dependence of the torque on the field applied along the antiferromagnetic axis in the ac plane of a

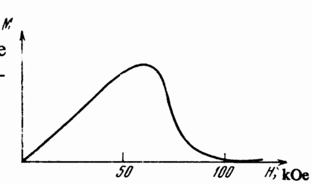


FIG. 2. Dependence of the torque (in relative units) on the external magnetic field applied along the antiferromagnetic axis of a europium orthoferrite single crystal, in the ac plane.

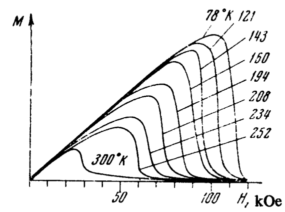


FIG. 3. Dependence of the torque on the magnetic field for a single crystal of $Eu_{0.25}Sm_{0.75}FeO_3$ at various temperatures. The field was applied along the antiferromagnetic axis in the ac plane.

single crystal of $EuFeO_3$ at room temperature. Initially, the torque increased with increasing field, but this was followed by a decrease of the torque because the weak ferromagnetic moment became oriented along the field when the antiferromagnetic sublattices were switched. The value of the threshold field for $EuFeO_3$ at room temperature was of the order of 75 kOe and, in contrast to $SmFeO_3$, was practically unaffected by cooling to 78°K.

A weak temperature dependence of the threshold field was observed also for $YFeO_3$, which exhibited, as in[5], a rotation of the magnetic moment by an external field. The room-temperature value of the threshold field of $YFeO_3$ was 70 kOe; at 78°K, this field was 72 kOe.

The observed strong temperature dependence of the threshold field of $SmFeO_3$ was evidently due to the fact that when this crystal was heated to 480°K, it exhibited a spontaneous reorientation of the magnetic moment from the a to the c axis of the orthorhombic crystal. It was clear that near this temperature the reorientation of the antiferromagnetic vector should take place in relatively weak fields and the value of the threshold (switching) field should increase away from the spontaneous reorientation temperature.

We also investigated single crystals of mixed orthoferrites $Eu_{0.25}Sm_{0.75}FeO_3$ and $Eu_{0.5}Sm_{0.5}FeO_3$, which also exhibited a spontaneous reorientation of the magnetic moment, with the reorientation regions centered on 380 and 280°K. Figure 3 shows the dependence of the torque on the intensity of the field applied at various temperatures along the antiferromagnetic axis of $Eu_{0.25}Sm_{0.75}FeO_3$. Similar curves were also obtained for $Eu_{0.5}Sm_{0.5}FeO_3$ below the reorientation temperature.

Figure 4 shows the temperature dependences of the threshold fields of $SmFeO_3$, $Eu_{0.25}Sm_{0.75}FeO_3$, and $Eu_{0.5}Sm_{0.5}FeO_3$, determined from the torque curves. As demonstrated in[3], the threshold field of orthoferrites is given by the relationship

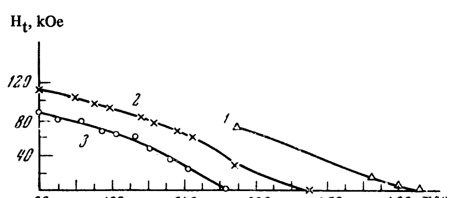


FIG. 4. Temperature dependences of the threshold fields of orthoferrites: 1) $SmFeO_3$; 2) $Eu_{0.25}Sm_{0.75}FeO_3$; 3) $Eu_{0.5}Sm_{0.5}FeO_3$.

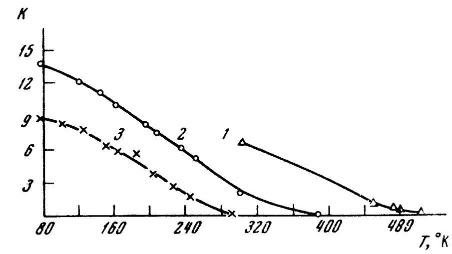


FIG. 5. Temperature dependences of the anisotropy constants (in units of $10^4$ erg/g) of orthoferrites: 1) $SmFeO_3$; 2) $Eu_{0.25}Sm_{0.75}FeO_3$; 3) $Eu_{0.5}Sm_{0.5}FeO_3$.

$$H_t = \left(H_0 H_A + \frac{H_D^2}{4}\right)^{1/2} - \frac{H_D}{2},$$

where $H_0$ is the exchange field; $H_A = 2K/M_0$ is the anisotropy field; $H_D$ is the Dzyaloshinskiĭ field. Substituting into this formula the values of the exchange field ($10^7$ Oe) and of the Dzyaloshinskiĭ field ($10^5$ Oe), which we found for lanthanum orthoferrite, and assuming that these fields did not vary greatly with temperature, we used the value of the threshold field to determine the anisotropy field and hence the anisotropy constant.

Figure 5 shows the temperature dependences of the anisotropy constants of Sm and mixed orthoferrites. The anisotropy constants of these compounds depended strongly on temperature, vanishing at the temperature of spin reorientation. On the other hand, the threshold field, and, consequently, the anisotropy field of europium and yttrium orthoferrites varied weakly with temperature and these orthoferrites did not exhibit the spontaneous reorientation of spins. This difference between the temperature dependences of the anisotropy constants of the investigated orthoferrites could be due to the fact that, in contrast to $Sm^{3+}$ ions, the total magnetic moment of $Y^{3+}$ and $Eu^{3+}$ ions was equal to zero and these ions exerted no influence on the crystal field of $Fe^{3+}$ ions, but this influence could be considerable in orthoferrites containing rare-earth ions with non-zero magnetic moments. It is likely that this is the reason why the phenomenon of magnetic moment reorientation has been observed so far only in those orthoferrites in which rare-earth ions have a magnetic moment.

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