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MAGNETIZATION IN SINGLE CRYSTALS OF SOME RARE-EARTH ORTHOFERRITES

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Single crystals of the rare-earth orthoferrites ($MFeO_3$) have been prepared[1] and their magnetic properties measured from room temperature to 1.3°K, for M=Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu. All of these have a "parasitic" spontaneous moment[2] of about 0.05 Bohr magneton per molecule at room temperature. However, we find that in $HoFeO_3$, for example, this moment increases rapidly at lower temperatures to about 3 Bohr units so that it can no longer be properly termed parasitic. Figure 1 shows the spontaneous moment per gram, σ_0, of most of the crystals examined. These results are obtained by extrapolation of the straight line $\sigma=\sigma_0+\chi H$ to H=0.

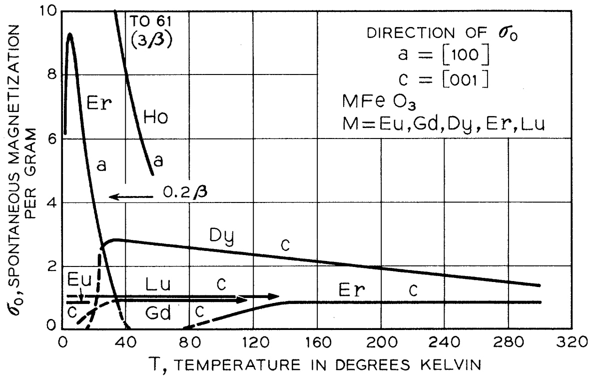

FIG. 1. Spontaneous magnetization and its direction as dependent on temperature, for a number of rare-earth orthoferrites.

At any given temperature, the direction of σ_0 is along either the [001] or the [100] orthorhombic axis.[3] All of the crystals measured, except $SmFeO_3$, have $\sigma_0 \parallel [001]$ at room temperature, and $ErFeO_3$ and $HoFeO_3$ show a change to [100] in the neighborhood of 60-80°K; in $YbFeO_3$ the change occurs at about 8°K as shown in Fig. 2.

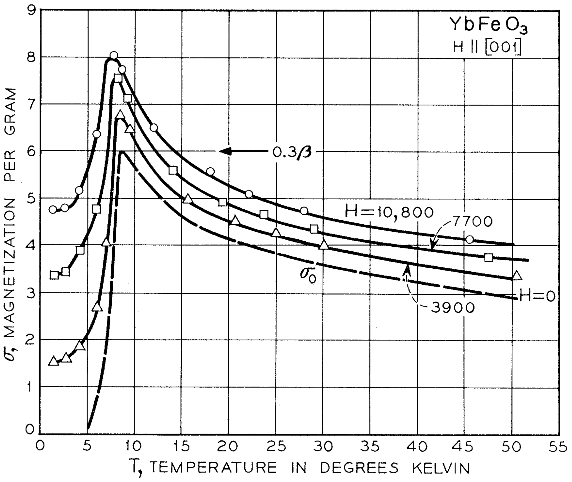

FIG. 2. Disappearance of $\sigma_0 \parallel [001]$ in $YbFeO_3$ below 8°K. It is then $\parallel [100]$ and rises to 19 per gram (about 0.9 β per molecule) at 1.3°K.

In $DyFeO_3$ σ_0 disappears on cooling at about 30°K.

The crystals that show a distinct rise in the magnitude of σ_0 at low temperatures are those that possess a net orbital moment: Ho, Er, Dy, and Yb orthoferrites; those that show no appreciable increase are Gd, Lu, and Eu. This suggests that interaction with the 4f orbitals is of primary importance in determining the directions of spin.

In high fields and low temperatures (12 500 oe, 1.3°K), the direction of greatest magnetization in $HoFeO_3$ is ∥ [010], whereas σ_0 ∥ [100]. Apparently the spins which have a resultant spontaneous magnetization ∥ [100] can be rotated most completely at right angles into the [010] direction. Magnetization of 4.5 Bohr magnetons is then attained, although σ_0 is only 3.0. In low fields (≈1000 oe), the measured susceptibility is lowest in the [001] direction, but the susceptibilities ∥ [001] and ∥ [010] both appear to approach zero at 0°K. The direction of the actual spins of the Ho ions is therefore not determined by the magnetic data; it is difficult to separate the two effects of spin direction and crystal anisotropy.

In $ErFeO_3$ at 1.3°K and 12 500 oe, the magnetization attains 5.7 Bohr units when magnetized ∥ [001], whereas at 4° σ_0 ∥[100] and is only 0.4 Bohr unit and becomes less at lower temperatures. In low fields the susceptibility is again low in both the [001] and [010] directions.

In $TbFeO_3$, the spontaneous magnetization at 4°K is 2 Bohr units ∥ [100]. The magnetization attains its highest value in this direction, not at 90° thereto as in $HoFeO_3$ and $ErFeO_3$, and is 5.2 Bohr units at 12 500 oe .

In high fields and low temperatures, the crystal anisotropies in $HoFeO_3$ and $ErFeO_3$, for example, are quite high as compared with that in $GdFeO_3$; the latter is almost isotropic when measured in fields of 10 000 oe, below 100°K. This is to be expected if the anisotropy originates in spin-orbit coupling.

In $DyFeO_3$ at 1.3°K, the form of the magnetization curves in the [100] and [010] directions is S-shaped with the steep rise in magnetization at about 7000 oe, the curve reaching to 7 Bohr units at 12 500 oe. Since we observe no spontaneous magnetization at this temperature, it is concluded that in zero applied field the spins are accurately antiferromagnetic, and are pulled from their original positions when a threshold field is applied at right angles.

We are indebted to Dr. W. C. Koehler for discussion of the results and to Mr. A. J. Williams for assistance with the measurements.

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[1] J. P. Remeika, J. Am. Chem. Soc. 78, 4259 (1956).

[2] H. Forestier and G. Guiot-Guillain, Compt. rend. 230, 1844 (1950); R. Pauthenet, Compt. rend, 242, 1859 (1956); Bozorth, Williams, and Walsh, Phys. Rev. 108, 157 (1957).

[3] The structure has been described by S. Geller, J. Chem. Phys. 24, 1236 (1956).

THERMAL EFFECTS OF THE MARTENSITIC TRANSITION IN SODIUM

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From metallographic[1] and x-ray[2] examination Barrett has deduced the existence of a martensitic transition in sodium. It appears that at temperatures below about 36°K, the body centered cubic lattice begins to change to a close packed hexagonal structure with stacking faults[2]. The proportion of close packed hexagonal lattice increases as the temperature is lowered (to perhaps about 5% at 4°K[1,2]).

Specific heat measurements have been made by the method of continuous heating using a modified form of the adiabatic apparatus described by Dauphinee *et al.*[3] The experimental runs were made in the following sequence.

(a) Sodium sample cooled to 40°K and specific heat measurements made to 98°K.

(b) Sample cooled to 40°K and measurements taken up to 100°K.

(c) Sample cooled to 2°K and measurements then made from about 20°K to 109°K.

(d) Sample cooled to 20°K and measurements made up to 92°K.

Finally,

(e) sample cooled to 40°K and measurements made to 84°K.

The cryostat was maintained at liquid nitrogen

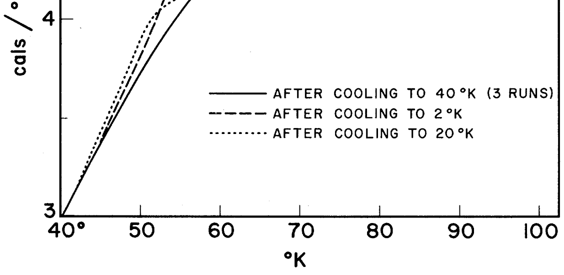

FIG. 1. Specific heat of sodium.