Temperature hysteresis of the magnetization in orthoferrites at the compensation point

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A first-order transition was observed in orthoferrites, for the first time, in a field near the compensation point. The value of the exchange field from the discontinuities of the magnetization on the phase boundaries with $\theta=0$ and $\theta=\pi$. A thermodynamic explanation of this phenomenon is offered.

Although the compensation point T_c in orthoferrites was observed relatively long ago, [1] there are still no data on the influence of the magnetic field on the character of the phase transition in this temperature region. We have investigated the magnetization of single-crystal $ErFeO_3$ and $Er_{0.8}Dy_{0.2}FeO_3$ in the region of T_c (45 and 25 °K, respectively). The single crystals were grown from the solution in the melt. The magnetization was measured with a vibration magnetometer.

It is known that the presence of a compensation point in orthoferrites is due to negative exchange interaction of the iron and rare-earth ions. The total spontaneous moment of an orthoferrite is, according to, [2]

$$M = M_0 + \chi_R H_0 \tag{1}$$

M_0 is the weak-ferromagnetic moment of the iron ions, χ_R is the paramagnetic susceptibility of the rare-earth ions, and H_0 is the exchange field produced at the rare-earth ions by the iron-ion spins. Owing to the strong temperature dependence of the paramagnetic susceptibility of the rare-earth ions, in the case of negative exchange interaction the induced magnetic moment of the rare-earth ions decreases the total magnetic moment and causes it to vanish at the compensation point. It was shown in[3,4] that in the presence of an external magnetic field H the compensation point in an iron garnet becomes a first-order phase transition point. The theoretical phase diagram for this case is shown in Fig. 1. It can be shown that for orthoferrites the phase diagram in the region of the compensation point should be similar in character.

Let us consider the behavior of orthoferrites with T_c in an external magnetic field $H \parallel M_0$ with allowance for the interaction of the rare-earth and iron ions. The free energy for this case can be expressed in the form

$$E = \frac{M_R^2}{2\chi_R} + M_R \frac{M_0}{|M_0|} H_0 - M_0 H - M_R H, \tag{2}$$

where M_R is the magnetic moment of the rare-earth ions. We assume that the exchange field is such that the signs of M_R and M_0 are different. Minimizing (2) with respect to M_R, we obtain

$$M_R = \chi_R\left(H - \frac{M_0}{|M_0|} H_0\right). \tag{3}$$

It is seen from (3) that $M_R = -\chi_R(M_0/|M_0|)H_0$ at $H=0$, and the compensation point will be observed if $\chi_R H_0 = M_0$. To find the equilibrium value of the energy, we substitute in (2) the value of M_R from (3)

$$E = -\frac{\chi_R H^2}{2} - \frac{\chi_R H_0^2}{2} - M_0 H\left(1 - \frac{\chi_R H_0}{|M_0|}\right). \tag{4}$$

The free energy will be minimal under the condition

$$M_0 H\left(1 - \frac{\chi_R H_0}{|M_0|}\right) > 0. \tag{5}$$

Consequently, at temperatures above T_c, where $\chi_R H_0 < |M_0|$, the weak-ferromagnetic moment exceeds zero and is directed along the field. Below T_c we have $\chi_R H_0 > M_0$ and $M_0 < 0$, i.e., it is directed opposite to the field. Thus, in the region of the compensation point the behavior of orthoferrites agrees qualitatively with the picture of Fig. 1. The figure shows also the region bounded by the curve NCK, in which the phases with $\theta=0$ and $\theta=\pi$ coexist (θ is the angle between the direction of the external field and that of the weak-ferromagnetic moment). The line CT_c is the first-order phase-transition line.

Figure 2b shows the temperature dependences of the magnetization obtained at $H=440$ Oe and 1170 Oe for the composition $Er_{0.8}Dy_{0.2}FeO_3$. We see that an appreciable magnetization hysteresis is observed, and the sample magnetization is reversed jumpwise at a definite temperature that depends on H. The observed jumps are attributed to the fact that the crystal magnetizations corresponding to the phases $\theta=0$ and $\theta=\pi$ are de-

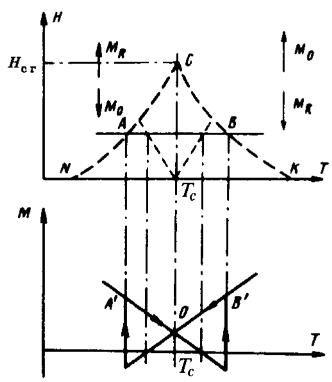

FIG. 1. Theoretical phase diagram of iron garnets.[4]

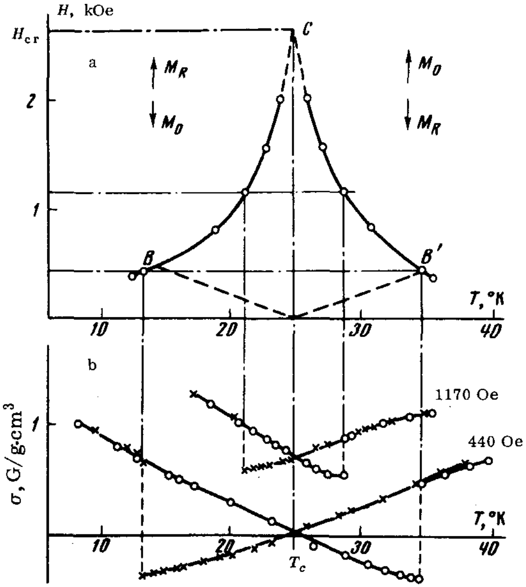

FIG. 2. Experimental temperature dependence of the coercive force H_c (a) and of the magnetization (b), ○—rising temperature, ×—falling temperature.

scribed by different relations:

$$M = M_0 + \chi_R H - \chi_R H_0, \quad \theta = 0,$$
$$M = -M_0 + \chi_R H + \chi_R H_0, \quad \theta = \pi. \tag{6}$$

From the magnetization jump we can determine the exchange field produced at the rare-earth ion by the iron ions; its value was found to be 2.6×10^3 Oe for $ErFeO_3$ and 2.1×10^3 Oe for $Er_{0.8}Dy_{0.2}FeO_3$. At $H\neq0$, the total magnetization vanishes at a temperature different from T_c. This field can be obtained from the condition

$$H = H_0\left(\frac{T - T_K}{T_K}\right). \tag{7}$$

Formula (7) was used to plot the zero-magnetization lines T_cB and T_cB' at $H_0 = 2.1\times10^3$ Oe (Fig. 2a).

Using the data on the magnetization (Fig. 2b), we plotted the phase diagram in the form of the dependence of the coercive force H_c (the field at which the sample magnetization is reversed) on the temperature. These data, which are shown in Fig. 2a, offer evidence that H_c increases when T_c is approached. This character of the dependence of the coercive force is connected with the decrease in the total magnetization when T_c is approached ($H_c \sim k/J_s$), and is apparently due to the fact that the magnetization-reversal process is effected by irreversible rotation of single-domain particles.

Our experimental and theoretical phase diagrams agree qualitatively with each other. The presence of hysteresis in the field and the abrupt jumps of the magnetization on going from the phase $\theta = 0$ to the phase $\theta = \pi$ offers evidence that the compensation point in a field $\mathbf{H} \parallel \mathbf{M}_0$ is a first-order phase transition.

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