Lifshitz critical point in yttrium orthoferrite in weak magnetic fields

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The differential susceptibility of yttrium orthoferrite was measured for magnetic fields in the range 0–35 Oe and for temperatures in the range 283–670 K. The compound $YFeO_3$ has a Lifshitz critical point, which arises due to rearrangement of the domain structure.

Multicritical phenomena, which are associated with phase transitions (PT) from a homogeneous state (HS) to commensurate and incommensurate structures (IS), have been studied extensively in recent years.[1,2] Transitions of this kind, which arise due to rearrangement of the domain structure, were predicted theoretically in magnetically ordered crystals and observed experimentally in quasiuniaxial epitaxial ferrite–garnet films.[3] In particular, it has been shown that films and plates fabricated from uniaxial ferrites-garnets exhibit Lifshitz critical points that separate lines of the phase transition from a homogeneous state to an incommensurate structure with $H \parallel$ EMA (easy-magnetization axis).

Orthoferrites which have a distorted perovskite structure, in which the antisymmetrical Dzyaloshinskiĭ–Mori exchange creates a weak transverse ferromagnetism with the spin configuration $G_x F_z$, are ideal objects for studying transitions to IS.[4] At high temperatures, the weak ferromagnetic moment F_z and the antiferromagnetism vector G_x of all orthoferrites are oriented along the [001] and [100] axes, respectively. The strong uniaxial magnetic anisotropy, the low value of the saturation magnetization M_s, and the high coefficient of domain formation of orthoferrites create the conditions for rearrangement of the domain structure and, therefore, realization of transitions from the HS to IS in weak magnetic fields $H \ll H_A$ (H_A is the anisotropy field).

In this letter we present the first experimental proof for the existence of a Lifshitz critical point in bulk crystals of yttrium orthoferrite with $H \parallel$ EMA, obtained from data on the temperature and field dependences of the differential magnetic susceptibility. The susceptibility χ was measured by the modulation method at a frequency of 78 Hz in the temperature range 283–670 K in magnetic fields of 0–35 Oe. A bulk crystal with an average demagnetizing field of 16.6 Oe was studied.

Typical curves of the dependence $\chi(H)$ and $\chi(T)$ are shown in Figs. 1 and 2. We see that the isotherm corresponding to $T = 283$ K contains two jumps in the susceptibility, one of which occurs at a value of H that coincides with the demagnetizing field of the sample. As the temperature is increased, the jumps in χ are displaced toward weak fields and at $T = 635$ K only one anomaly remains. These characteristics of χ are also manifested in the temperature dependence of the susceptibility (Fig. 2). In the absence of a magnetic field, the susceptibility remains with increasing T essentially constant up to $T = 590$ K, and then falls off to zero, without manifesting the anomalies characteristic of magnetically ordered crystals.[5] At $T = 643.4$ K, the Curie tem-

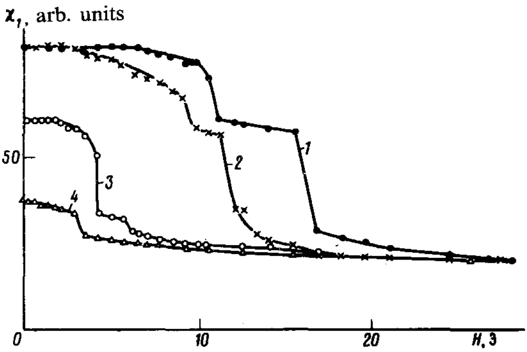

FIG. 1. Isotherms of the field dependence of the susceptibility of $YFeO_3$ for different T. 1 — 283.16 K; 2 — 515 K; 3 — 626.4 K; 4 — 635 K.

perature T_c, χ passes through a small peak, which is observed with both heating and cooling. In magnetic fields up to 3.3 Oe, the curve of χ versus T does not change, but the temperature at which the hysteresis-free peak occurs is displaced toward low temperatures as H is increased. Beginning with $H = 3.43$ Oe, the curve $\chi(T)$ exhibits two jumps in the susceptibility, which move toward low temperatures as H is increased. In a 14.7-Oe field, there is only one jump in χ, which corresponds to $T = 290$ K. Cooling from the paramagnetic phase to the magnetically ordered phase with $H > 3.43$ Oe proceeds irreversibly, and there is no susceptibility over the entire range of temperatures studied. This circumstance indicates a significant "supercooling" of the homogeneous state, i.e., the state in which there is no domain structure and the magnetization direction coincides with H.

It follows from these experimental data that a second-order PT occurs in the range of magnetic fields 0–3.3 Oe, whereas for $H > 3.43$ Oe at least two first-order PT

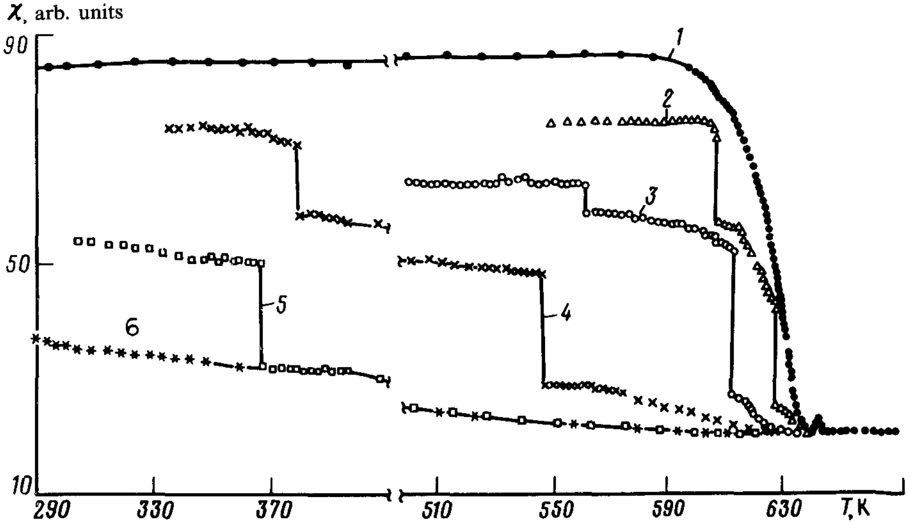

FIG. 2. Temperature dependence of χ in magnetic fields of various intensities. 1—0 Oe; 2—5.6 Oe; 3—7 Oe; 4—11.2 Oe; 5—14 Oe; 6—15.4 Oe.

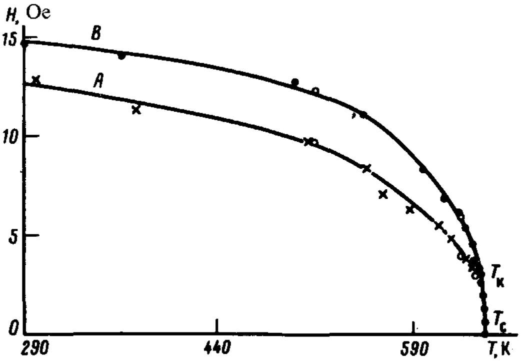

FIG. 3. H–T diagram of yttrium orthoferrite.

are observed. The phase diagram corresponding to these transitions is shown in Fig. 3. The characteristics of the H–T diagram for $YFeO_3$ can be qualitatively explained as follows. In yttrium orthoferrite, we have $H_p \ll H_A$ ($H_A \sim 10^5$ Oe), so that the formation of a domain structure without closure domains should be expected. In the absence of a magnetic field, a labyrinth-type band domain structure[6] (BDS) is formed. This structure transforms to a regular BDS as H is increased, since cylindrical domains are unstable in bulk crystals. A further increase of H causes a transition to a uniformly magnetized state at $H = H_p$. Near T_c and $H < 3.3$ Oe, there is, as demonstrated in Ref. 3, an unusual BDS, for which the amplitude of the inhomogeneity M is lower than the magnetization induced by the magnetic field. In the phase diagram the curve $T_c T_k$ therefore corresponds to the second-order phase-transition line on which the transition from the incommensurate (domain) structure to the homogeneous state occurs; the $T_k A$ and $T_k B$ lines are the lines for the loss of stability of transitions from one type of IS to another and to the HS. On the $T_k A$ line, the phase with an amorphous domain structure becomes unstable with respect to a transition to the BDS, while on the $T_k B$ line the regular BDS becomes unstable with respect to a transition to the HS. The lines for the loss of stability of the inverse transitions have not been observed experimentally.

In summary, the critical point with the coordinates $T_k = 638$ K and $H_k = 3.3 \pm 0.1$ Oe, which separates the first- and second-order phase-transition lines, can be interpreted as a Lifshitz point.

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[1] Yu. A. Izyumov and V. M. Laptev, Abstracts of Reports at the All-Union Symposium on Inhomogeneous Electronic States, Novosibirsk, 1984, p. 24.
[2] R. M. Hornreich, J. Magn. Magn. Mater. **15–18**, 387 (1980).
[3] E. E. Dikshteĭn, F. V. Lisovskiĭ, E. G. Mansvetova, and V. V. Tarasenko, Fiz. Tverd. Tela **25**, 2545 (1983) [Sov. Phys. Solid State **25**, 1465 (1983)].
[4] K. P. Belov, A. K. Zvezdin, A. M. Kadomtseva, and R. Z. Levitin, Orientatsionnye perekhody v redkozemel'nykh magnetikakh (Orientational Transitions in Rare-Earth Magnets), Nauka, Moscow, 1979.
[5] I. K. Kamilov and Kh. K. Aliev, Usp. Fiz. Nauk **140**, 639 (1983) [Sov. Phys. Usp. **28**, 696 (1983)].
[6] R. C. Sherwood, J. P. Remeika, and H. J. Williams, J. Appl. Phys. **30**, 217 (1959).

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