Investigation of the critical behavior of yttrium orthoferrite $YFeO_3$ with the aid of the Mössbauer effect

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The critical behavior of single-crystal $YFeO_3$ in an external magnetic field $\mathbf{H} \parallel [c]$ has been investigated, for the first time, with the aid of the Mössbauer effect. The obtained values of the critical exponents ($\beta = 0.36 \pm 0.01$; $\delta = 4.0 \pm 0.4$; $\gamma = 1.0 \pm 0.2$) satisfy the scaling-hypothesis relations. A change in the "cant" angle of the sublattices is observed in the region $T \approx T_N$.

Investigations of critical phenomena in second-order phase transitions, aimed at studying the equations of the magnetic state, are being extended to include an ever increasing number of substances with different types of magnetic structure. Recently, interest in research of this type in antiferromagnets with weak ferromagnetism (AWF) has noticeably increased.

As is well known, at the dominant antiferromagnetic type of order, the AWF have a spontaneous magnetic moment **m** due to the small "cant" of the magnetizations $\mathbf{M}_i$ of the sublattices ($i = 1, 2$ in the two-sublattice model), owing to the Dzyaloshinskiĭ interaction.[1] Because of this interaction, near the Neel temperature T_N, an external magnetic field **H** restores the magnetic order of the AWF at $T \gtrsim T_N$, and increases the magnetic order at $T \lesssim T_N$ (effect of field-induced antiferromagnetism[2]). This induction effect was observed in a number of AWF with the aid of AFMR,[3] NMR,[4] and the Mössbauer effect (ME).[5,6]

This feature of AWF makes it possible to investigate their critical behavior by methods that are sensitive directly to the order parameter $\mu(T,H) = M(T,H)/M(0,0)$. So far, however, a systematic study of the AWF in the critical temperature region has been carried out mainly with the aid of magnetic measurements, owing to their relative simplicity and accessibility. Yet magnetic measurements yield only indirect information on the value of $\mu(T,H)$, since the measured quantity **m** depends on the "cant" angle α of the AWF sublattices, which in turn can vary as $T \to T_N$. On the other hand, the use of such a method as the Mössbauer effect makes it possible (in the case when the hyperfine field $\mathbf{H}_{hf}$ is proportional to the magnetic moment M) to obtain direct information on the value of $\mu(T,H)$, thereby affording a simple and convenient method for the study of the critical behavior of certain AWF.

In the present paper we chose to investigate the yttrium orthoferrite $YFeO_3$, which has already been studied in sufficient detail in the critical-temperature region by magnetic measurements.[7,8] It has turned out, however, that not only were the conclusions drawn by the authors of these papers concerning the character of the critical behavior of $YFeO_3$ quite contradictory, but the very values of the critical exponents (β, δ, γ) differed greatly. We have therefore undertaken detailed investigations of the critical behavior of single-crystal $YFeO_3$ with the aid of the Mössbauer effect. The favoring circumstance in this approach is that a proportionality between $\mathbf{H}_{hf}$ and **M** has been experimentally established for $YFeO_3$ in the temperature interval $0.50 < T/T_N < 0.95$.[9,10]

Measurements of the Mössbauer effect were made with a single-channel γ spectrometer operating in the constant-source-velocity regime (the source was Co^{57} in

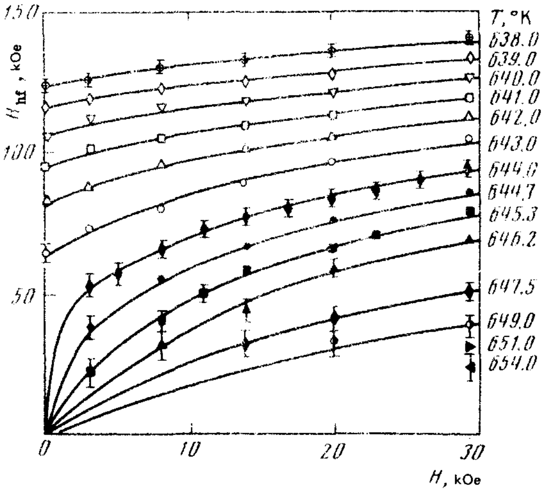

FIG. 1. Plots of H_{hf} at Fe^{57} nuclei on T and H in $YFeO_3$ in the critical region.

Cr). The sample was a plate measuring $1 \times 1 \times 0.01$ cm, with the [c] axis in the plane of the polished surface. A field $\mathbf{H} \parallel [c]$ was applied perpendicular to the direction of the γ quanta. The sample temperature was maintained constant during the course of the measurements with accuracy not worse than $\pm 0.1°$; the critical temperature ($T_N = 644.0 \pm 0.1$ °K) was determined by the thermal scanning method. The obtained Mössbauer spectra were reduced with a computer by least squares with the line shape approximated by a Lorentz curve. The value of H_{hf} was calculated from the formula $H_{hf} = (H_n^2 - H^2)^{1/2}$, where H_n is the measured effective field at the Fe^{57} nucleus in $YFeO_3$, and H is the external field.

Figure 1 shows the "magnetization isotherms" $H_{hf}(T, H)$ in the critical region at $\mathbf{H} \parallel [c]$. From these data, assuming

$$H_{hf}(T, 0) \sim (T_N - T)^{\beta}, \quad (T \leqslant T_N); \quad H_{hf}(T_N, H) \sim H^{1/\delta};$$

$$\left.\frac{\partial H_{hf}(T, H)}{\partial H}\right|_{H \to 0} \sim \left| T - T_N \right|^{-\gamma}$$

we obtained the values of the critical exponents for $YFeO_3$:

$$\beta = 0.36 \pm 0.01, \quad (0.90 < T/T_N < 0.9998);$$
$$\delta = 4.0 \pm 0.4, \quad (0 < H < 30 \text{ kOe});$$
$$\gamma = 1.0 \pm 0.2, \quad (0.001 < |1 - T/T_N| < 0.01).$$

These values, with the limits of the experimental error, satisfy the fundamental equation $\beta(\delta - 1) = \gamma$ of the scaling hypothesis. [11]

According to this hypothesis, the equation of state of a magnet in the critical temperature region takes the form

$$\frac{M}{|T - T_N|^{\beta}} = f\left(\frac{H}{|T - T_N|^{\beta\delta}}\right),$$

where f is the so-called "scaling function." A plot of the function f obtained from the $H_{hf}(T, H)$ data is shown

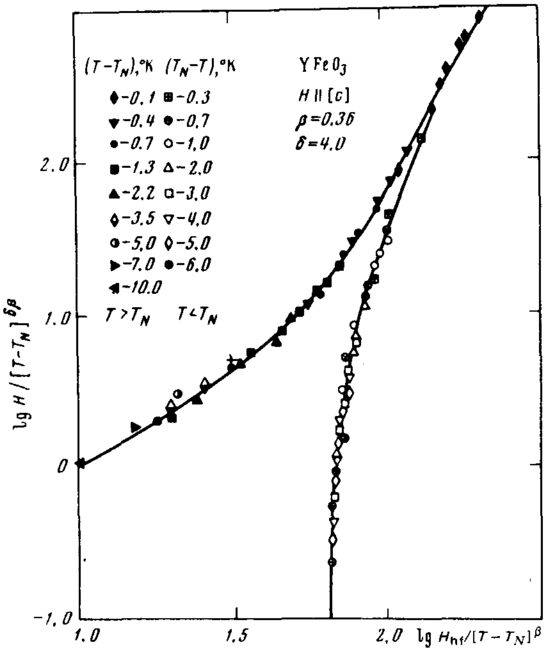

FIG. 2. Plot of the "scaling function" for $YFeO_3$.

in Fig. 2 (in a logarithmic scale). It is seen from the plot that the experimental values of $H_{hf}(T, H)$ are fitted by two curves ($T < T_N$ and $T > T_N$) that converge together as $T \to T_N$. This result confirms the fact that the critical behavior of $YFeO_3$ satisfies the scaling-hypothesis requirement.

The values of the critical exponents for $YFeO_3$ are close to the values typical of ordinary ferro- and ferrimagnets, but differ significantly from the values obtained from magnetic measurements ($\beta = 0.47 \pm 0.05$; $\delta = 5.1 \pm 0.5$; $\gamma = 2.0 \pm 0.2$ [8]). This discrepancy can apparently be attributed to the dependence of the "cant" angle α on T and H, which violates the proportionality between $m(T, H)$ and $M(T, H)$ in the critical temperature

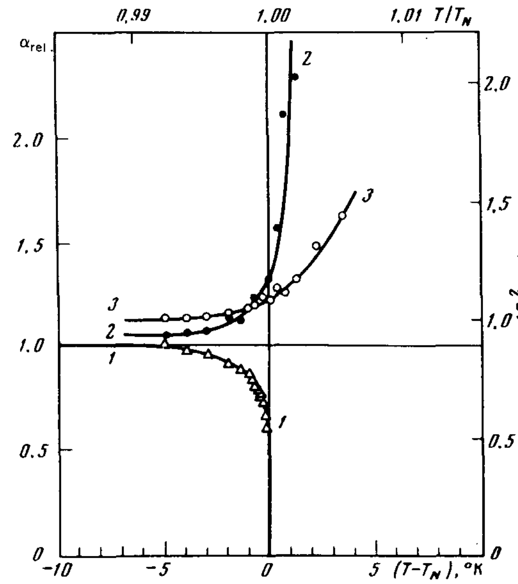

FIG. 3. Temperature dependence of the "cant" angle of the sublattice magnetizations of the $YFeO_3$: 1—$H = 0$; 2—$H = 4$ kOe; 3—$H = 15$ kOe.

region. The results obtained with allowance for the data on the magnetic measurement[8] (Fig. 3) show that $\alpha(T,H)$ is a nonanalytic function in the region $T \approx T_N$. It is possible that this may be due to the fact that near T_N the fluctuations of the long-range magnetic order are so large that the concept of the "cant" angle of the AWF sublattices becomes meaningless.

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