"Splitting" of the critical exponents of the sublattice magnetizations in Fe_3BO_6

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Mössbauer spectroscopy is used to investigate the critical behavior of the antiferromagnet Fe_3BO_6. It is observed that different critical exponents correspond to the two pairs of antiferromagnetic sublattices.

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Many papers devoted to critical phenomena in phase transitions into a magnetically ordered state have been published by now, and give the critical parameters and the relations between them. The studies, however, were either devoted usually to ferromagnets or antiferromagnets with two magnetic sublattices, or were made, in the case of compounds with a large number of sublattices, by methods that did not distinguish between the magnetic subsystems. We report here the use of the Mössbauer effect to distinguish between nonequivalent sublattices in an investigation of the critical behavior of an antiferromagnet with a weak ferromagnetic moment (AWF), Fe_3BO_6, in which the iron ions occupy nonequivalent positions and the magnetic subsystem breaks up into four sublattices.

Fe_3BO_6 has an orthorhombic structure (space group P_{nma}).[1] The iron ions occupy the positions 8*d* and 4*c*. The Néel temperature is $T_N \approx 508$ K.[1,2] Above 415 K, the ferromagnetic moment is directed along the *C* axis, and below this temperature along the *a* axis.[3]

For Mössbauer investigations, we used as absorbers either mosaics or individual single crystals in the form of thin plates with the *a* axis perpendicular to the plane of the plate. In the investigation of the temperature dependences, the temperature gradient in the sample was less than 0.01 K. The temperature was maintained within ± 0.04 K in measurements in an external magnetic field, and within ± 0.015 K without the field. The absolute temperature measurement error did not exceed ± 0.3 K.

From the experimental spectra we determined with a computer, assuming a Lorentz line shape, the positions of the hyperfine structure lines, and calculated the effective magnetic fields at the iron nuclei (H_{hf}). We have thus obtained the temperature dependences of the effective fields. It was further assumed that the effective fields are proportional to the magnetizations of the sublattices and have a power-law dependence near the Néel point:

$$H_{hf}(T)/H_{hf}(0) = D(1 - T/T_N)^{\beta}. \quad (1)$$

The quantities D, T_N, and β were determined by fitting the relation (1) to the experimental data by least squares with a computer, using a program based on a linearization method, with β, D, and T_N regarded as independent variables. The re-

TABLE I.

	8d	4c	
β	0.332	0.287	± 0.007
δ	4.6	5.1	± 0.4
T_N	507.7	507.6	± 0.03

sults are listed in Table I. The experimental value of $H_{\rm hf}$ at $T=4.2$ K, namely 521 kOe, was taken to be $H_{\rm hf}(0)$. The exponents β were determined also by the procedure of[4] and the same values were obtained. The main difficulty in the determination of the exponents lies in the fact that the lower temperature limit of the applicability of (1) is not known exactly beforehand, so that it is necessary to use the data closest to T_N. However, to obtain unambiguous results, the fit to relation (1) must be carried out in a sufficiently broad temperature range.

The exponents β were determined for different temperature intervals, all with the same upper temperature (507 K). It turned out that in any temperature interval in the range ($0.94 \leqslant T/T_N \leqslant 0.9988$) the smallest systematic deviations of the experimental data from (1) are obtained with the values of β listed in Table I. Thus, in a wide range of temperatures, there is good agreement between the experimental $H_{\rm hf}(T)$ dependence and the power law (1) (Fig. 1).

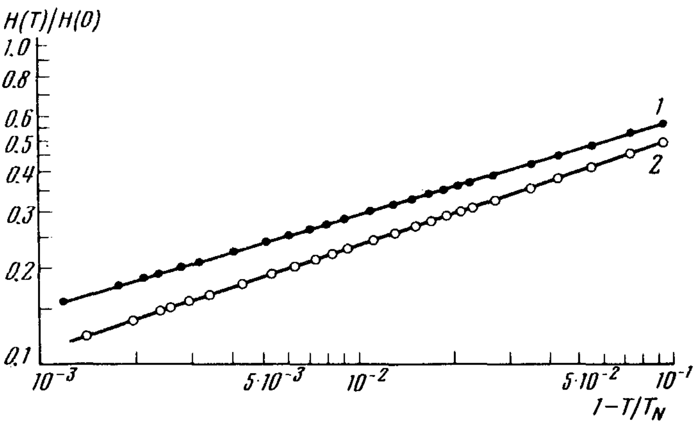

FIG. 1. Dependence of the logarithms of the relative magnetizations on the relative temperature in Fe_3BO_6 near the critical point (1,2—for the 4c and 8d positions of the iron ions).

Because of the Dzyaloshinskiĭ interaction in AWF such as Fe_3BO_6, an external magnetic field H applied along the weak ferromagnetism axis restores the antiferromagnetic order at $T \geqslant T_N$ and increases it at $T < T_N$.[5] This singularity of the AWF makes it possible to investigate their critical behavior with the aid of the Mössbauer effect[6] under the assumption that:

$$H_{hf}(T_N, H) \sim H^{1/\delta}. \quad (2)$$

Here H_{hf} is the hyperfine interaction field and is determined from the formula $H_{hf} = (H_{eff}^2 - H^2)^{1/2}$, where H_{eff} is the mèasured effective magnetic field at the iron-ion nuclei in the external field H. Using the induction effect, we obtain the experimental plots of (2) by applying an external field along the C axis (Fig. 2), and determine

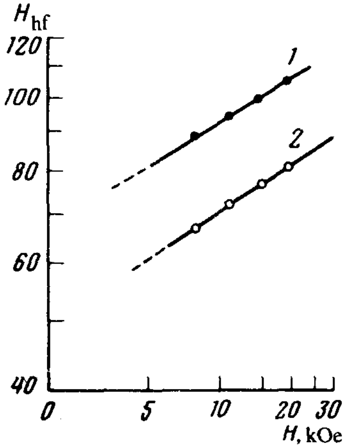

FIG. 2. Dependence of the logarithms of the hyperfine field on the external field in Fe_3BO_6 at $T = T_N$ (1,2—for the 4*c* and 8*d* positions of the iron ions).

the exponents δ listed in Table I.

As seen from Table I, the values of both β and δ obtained for nonequivalent magnetic subsystems were different, and the difference between the critical exponents β greatly exceeds the error in their determination.

We note that the magnetic subsystems of the ions in 8*d* and 4*c* positions are strongly coupled by exchange interaction, as can be seen from even a simple analysis of the crystal structure. It appears that for other compounds with magnetic ions occupying nonequivalent positions the critical indices pertaining to different subsystems will also be different and have the meaning of effective critical exponents of the subsystem.

A theoretical analysis of the behavior of systems of this type is contained in[7], where it is shown that interaction of antiferromagnetic systems greatly influences their critical behavior, leading, in particular, to a "splitting" of the values of the effective critical exponents pertaining to individual pairs of sublattices.

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