

Critical exponents of a system with isotropic multicomponent order parameter

L. M. Khriplovich

Institute of Inorganic Chemistry, Academy of Sciences of the USSR

(Submitted 9 August 1982)

Pis'ma Zh. Eksp. Teor Fiz. **36**, No. 6, 219–221 (20 September 1982)

The critical exponents of the specific heat near the Néel point T_N are determined experimentally for a system with an isotropic four-component order parameter (Co_3O_4). It is shown that the experimental value of α agrees with the value obtained with the renormalization-group method using the ϵ expansion only for $R > T_N$.

PACS numbers: 75.30.Kz, 75.40. — s

Verification of the predictions of the isotropic theory developed for systems with multicomponent order parameters¹ is complicated by the fact that the multicomponent nature itself, as a rule, is a result of crystalline anisotropy, and for this reason crystalline anisotropy, together with the dimensionality of the space, determines the values of the critical exponents. In this respect, the antiferromagnetic phase transition in Co_3O_4 , in which the multicomponent nature of the order parameter is not related to crystalline anisotropy, can serve as a model for studying the isotropic theory of phase transitions.

Co_3O_4 is a normal spinel with structural formula $\text{Co}^{2+}[\text{Co}_2^{3+}]\text{O}_4$. In addition, only ions Co^{2+} have a nonvanishing moment.² The ions Co^{2+} form a diamond structure which forms a fcc lattice. The structure and filling of the orbitals of the Co^{2+} ion in a tetrahedral field were also analyzed in Ref. 2. As shown in Ref. 3, antiferromagnetic ordering of spins of Co^{2+} is described by a four-component order parameter. It is important to note that the dimensionality of the order moment here is not related to the directions of crystalline anisotropy.

According to the renormalization-group method, in approximating the temperature dependence of the specific heat in the region of the transition by a power law

$$(C_p - C_r) \sim T = A + B\tau^{-\alpha} \quad (1)$$

the critical exponent, calculated with the help of the ϵ expansion up to terms of order ϵ^3 , is equal to $\alpha = -0.10$ in this case.

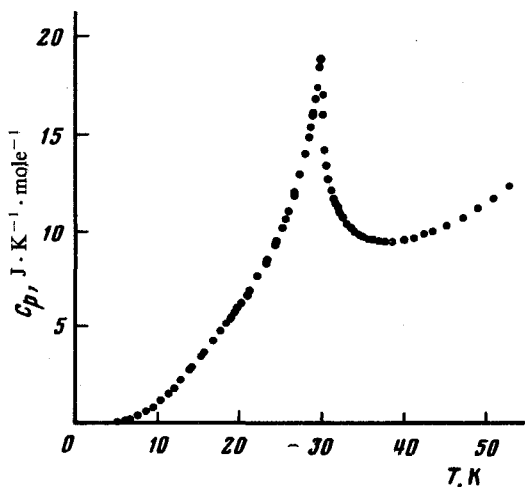


FIG. 1. Experimental values of the specific heat of Co_3O_4 near the Néel point.

In order to check the theoretical predictions experimentally, we measured the specific heat of a specimen of Co_3O_4 using vacuum adiabatic calorimetry.⁴ The polycrystalline specimen examined was obtained by a chemical transport reaction at the Central Institute of Solid State Physics and Materials Engineering of the Academy of Sciences of the German Democratic Republic. The specimen formed a single phase according to an x-ray diffraction analysis: weight composition corresponds to CoO_x , where $x = 1.332_0 - 1.333_0$; impurity content is $\sim 10^{-6}$ at. %.

The specific heat was measured from 5.1 to 307.34 K at 131 experimental points, whose averaged spread varied from 0.66% in the interval 5.1–13 K to 0.14% for 13–30 K, 0.37% for 30–60 K, and 0.03% for 60–307.34 K. A sharp peak was observed on the curve $C_p(T)$ at ~ 30 K (Fig. 1). The position of this peak coincides with the maximum of an arbitrary magnetic susceptibility of our specimen. The magnetic susceptibility was measured by the Faraday method in the interval 4.3–300 K in a 10-kOe field. The absence of any signs of a first-order phase transition was monitored with the help of thermograms. Hysteresis was not observed in $C_p(T)$ near the Néel point T_N (with an accuracy of ~ 0.05 K). The allowed representing the regular component of the specific heat C_r by a single combination of Debye-Einstein functions. From 70 to 300 K, i.e., in the entire temperature range of measurements, where the specific heat is not distorted by a phase transition, this combination of functions coincides with $C_p = (T)$ to within $\pm 1\%$. The magnitude of C_p near T_N is $\sim 1000\%$ of C_r .

Approximation of the experimental data by Eq. (1) gives the values $\alpha = -(0.11 \pm 0.02)$ and $\alpha' = -(0.18 \pm_{0.09}^{0.06})$, above the below T_N , respectively. The values of the Néel temperature obtained are $T_N = (29.93 \pm_{0.04}^{0.03})$ K and $T_N = (30.09 \pm_{0.17}^{0.26})$ K, which coincides with the position of the maximum on the specific heat curve. The temperature intervals, in which stationary solutions for α and T_N exist, were determined by varying the number of points included in the analysis at the boundaries: $0.34 \gg \tau \gg 1.8 \times 10^{-2}$ for $T < T_N$ and $0.43 \times 10^{-2} \ll \tau \ll 0.69$ for $T > T_N$. In addition, the quantities α and T_N were determined in the region $T > T_N$ using the experimental points belonging to the interval $0.51 \times 10^{-2} \ll \tau \ll 0.2$. The results obtained

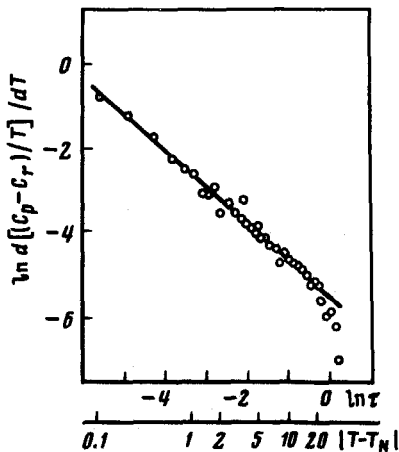


FIG. 2. $\ln d[(C_p - C_r)/T]/dT$ as a function of $\ln \tau$ for $T > T_N$ assuming that $T_N = 29.93$ K.

confirm the existence of a stable solution for α and T_N in the entire interval up to $\tau = 0.69$, which is illustrated in Fig. 2. The adequacy of the approximation was investigated by analyzing the residuals. This analysis, as well as the determination of the boundaries of regions of the stable solution and the confidence intervals of the parameters were performed using the Fisher criterion with 95% statistical reliability.⁵ The above-indicated confidence intervals of the parameters reflect the spread in the experimental points and their correspondence to (1). Including the errors in C_r increases the confidence intervals insignificantly. For example, including this additional circumstance for $T < T_N$, yields $\alpha' = -(0.18 \pm_{0.11}^{0.08})$ and $T'_N = (30.09 \pm_{0.19}^{0.28})\text{K}$, also with confidence probability 0.95.

Thus, the theoretical value $\alpha = -0.10$, which corresponds to the classical four-dimensional order parameter in the isotropic model and which is indeed obtained with the help of the ϵ expansion up to terms of order ϵ^3 , agrees well with the experimental value $\alpha = -(0.11 \pm 0.02)$. It is necessary to emphasize, however, the disagreement obtained between the experimentally observed values of α above and below the transition, inconsistent with the generally accepted theory. In this connection, further theoretical investigations of the description of the critical behavior obtained are desirable.

I thank E. V. Kholopov, without whose participation this work would not have been completed, as well as V. G. Bessergenev for kindly providing the program for analyzing the adequacy of the approximation.

¹K. Wilson and J. Kogut, Renormalization Group and the α Expansion, Mir, Moscow, 1975.

²W. L. Roth, J. Phys. Chem. Solids **25**, 1 (1964).

³V. N. Ikorskii, I. E. Paukov, E. V. Kholopov, and L. M. Khriplovich, Abstracts of Reports at the 21st All-Union Conference on the Low-Temperature Physics, Kharkov, 1980, p.163.

⁴L. M. Khriplovich, G. Opperman, and I. E. Paukov, Zh. Fiz. Khim. **53**, 1608 (1979).

⁵D. Hummelblau, Analysis of Processes by Statistical Methods, Mir, Moscow, 1973.

Translated by M. E. Alferieff

Edited by S. J. Amoretty