Quantum and classical aspects of a low-temperature ($\sim$500 mK) magnetic phase transition in aluminoborates

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Specific heat, C_B, of $R\mathrm{Al_3(BO_3)_4}$ single crystals with R = Tb, Dy, Gd was studied for 50 mK $< T <$ 300 K, with emphasis on the $T < 1$ K range, where a phase transition was found. For the Tb compound, which will be analyzed further as an example, the transition appears at $T_c = 0.68$ K. Nuclear, non-phonon, and lattice contributions to C_B were separated. Based on C_B and magnetization, M, studies, we established that the phase transition shifts to lower temperatures with increase in magnetic field $\mathbf{B}_{||}$, parallel to the easy magnetization axis. We found that the critical, i.e., related to the transition, contribution to the specific heat, C_{cr}, shows an unusual $C_{\mathrm{cr}} \sim T^{y_0}$ dependence on T, and that the Grüneisen ratio, Γ, defined as:

$$\Gamma = -\frac{1}{T}\frac{(\partial S/\partial B)_T}{(\partial S/\partial T)_B} = -\frac{(\partial M/\partial T)_B}{C_B\,(T)} = \frac{1}{T}\left(\frac{\partial T}{\partial B}\right)_S, \tag{1}$$

where S is entropy, diverges as a function of $B_{||}$ for $B_{||}$ approaching a critical value of 0.6 T. The behaviors of both C_{cr} and Γ as a function of T (especially scaling of Γ for $B_{||} \geq 0.30$ T), and dependence of Γ on $B_{||}$ are characteristic of systems, in which the classical phase transition line is influenced by quantum fluctuations, QF, and ends at quantum critical point. Using the determined y_0 and Γ values, we assessed the dynamical critical exponent z to be $0.82 \leq z \leq 0.96$. Based on these results, we suppose that QF dominate the behavior of the system and destroy the long range order, i.e., we suppose the transition found to have a quantum character. Its physical nature is not clear. The interpretation that this is the transition to the ferromagnetic ordering of $\mathrm{Tb^{3+}}$ magnetic moments is the most natural and supported by the M studies. However, such a classical transition should be smeared and shifted to higher T by $B_{||}$, while we observe the opposite effect. It was observed, e.g., in systems, in which exchange and magnetic dipolar interactions were of similar strength [1]. Also the possibility, that the transition is related to any other ordering , e.g., multipolar, and the ordering of the $\mathrm{Tb^{3+}}$ moments is a "side effect" only can not be ruled out.

References:

[1] G. Mennenga, L.J. de Jongh, W.J. Huiskamp, *J. Magn. Magn. Mater.* **44**, 59 (1984).

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