

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

T. Zajarniuk,¹ A. Szewczyk,¹ P. Wiśniewski,² M. U. Gutowska,¹
R. Puźniak,¹ H. Szymczak,¹ I. Gudim,³ V. A. Bedarev,⁴ and P. Tomczak⁵

¹*Institute of Physics, Polish Academy of Sciences, Warsaw, Poland*

²*Institute of Low Temperature and Structure Research, PAS, Wrocław, Poland*

³*Kirensky Institute of Physics, Krasnoyarsk, Russia*

⁴*B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, Kharkiv, Ukraine*

⁵*Faculty of Physics, Adam Mickiewicz University, Poznań, Poland*

Specific heat, C_B , of $RA\text{l}_3(\text{BO}_3)_4$ single crystals with $R = \text{Tb, Dy, Gd}$ was studied for $50 \text{ mK} < T < 300 \text{ K}$, with emphasis on the $T < 1 \text{ K}$ range, where a phase transition was found. For the Tb compound, which will be analyzed further as an example, the transition appears at $T_c = 0.68 \text{ K}$. 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 B_{\parallel} , 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 $C_{\text{cr}} \sim T^{y_0}$ dependence on T , and that the Grüneisen ratio, Γ , defined as:

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

where S is entropy, diverges as a function of B_{\parallel} for B_{\parallel} 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 $B_{\parallel} \geq 0.30 \text{ T}$), and dependence of Γ on B_{\parallel} 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 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_{\parallel} , 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 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).

This work was supported partially by the National Science Centre, Poland, under project No. 2018/31/B/ST3/03289.