Low-temperature magnetic phase transition in $TbAl_3(BO_3)_4$ - quantum and classical aspects

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Specific heat, C_B, of a $TbAl_3(BO_3)_4$ single crystal was studied for temperatures, T, from 50mK to 300 K, with emphasis on the $T < 1$ K range, where a phase transition was found at 0.68 K. Nuclear, non-phonon, and lattice contributions to C_B were separated. Based on the C_B and magnetization, M, studies, we found that: (i) the phase transition shifts to lower temperatures with increase in magnetic field $B_{\|}$, parallel to the easy magnetization axis, (ii) the critical, i.e., related to the phase transition, contribution to the specific heat, C_{cr}, shows an unusual dependence on T, $C_{cr} \sim T^{y_0}$, where y_0 is a positive exponent, and (iii) the Grüneisen ratio, Γ, defined as:

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

where S denotes entropy, diverges as a function of $B_{\|}$ for $B_{\|}$ approaching a critical value of 0.6 T. The determined behaviors of both C_{cr} and Γ as a function of T (especially scaling of the latter for $B_{\|} \geq 0.30$ T), as well as dependence of Γ on $B_{\|}$ are characteristic of the systems, in which the classical phase transition line is influenced by quantum fluctuations, QF, and ends at a quantum critical point. Based on the determined y_0 and Γ values, we assessed the dynamical critical exponent z to be $0.82 \leq z \leq 0.96$. Taking into account all 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.

The physical nature of the transition is not clear. The interpretation that this is the transition to the ferromagnetic order of Tb^{3+} magnetic moments is the most natural, intuitive, 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. Such effect was observed in systems, in which not only the exchange interactions but also magnetic dipolar interactions are essential [1]. However, the possibility, that the transition is related to any other kind of ordering, e.g., a multipolar ordering, and the ordering of the Tb^{3+} moments is a “side effect” only, can not be ruled out *a priori*.

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