μSR investigation of a quantum criticality in the coupled spin ladder Ba_2CuTeO_6

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Quantum spin ladders consisting of leg and rung couplings offer an outstanding opportunity to investigate quantum-critical spin dynamics and have far-reaching relevance to diverse fields of physics such as Tomonaga-Luttinger liquids, magnon fractionalization, unconventional superconductivity, and quark confinement.[1)-3)] Isolated two-leg ladders have a short-range resonating valence bond state.[4)] With growing interladder couplings, a quantum phase transition is anticipated to occur to the magnetically ordered state.[5)]

Ba_2CuTeO_6 is a prime candidate material for a three-dimensionally networked spin ladder, allowing addressing quantum criticality in coupled two-leg ladders. Ba_2CuTeO_6 features both a long-range ordering at T_N =15 K and the spin-gap excitation of Δ=50 K at finite temperatures.[6)-7)] However, the magnetic transition is largely hidden, while showing no magnetic Bragg peaks and no apparent λ-like anomaly in the specific heat. Thus, it is highly desired to identify the occurrence of the static magnetic ordering. To resolve these issues, we performed zero-field μSR experiments on the ARGUS spectrometer of RIKEN-RAL. The collected data were analyzed using the software package WiMDA.

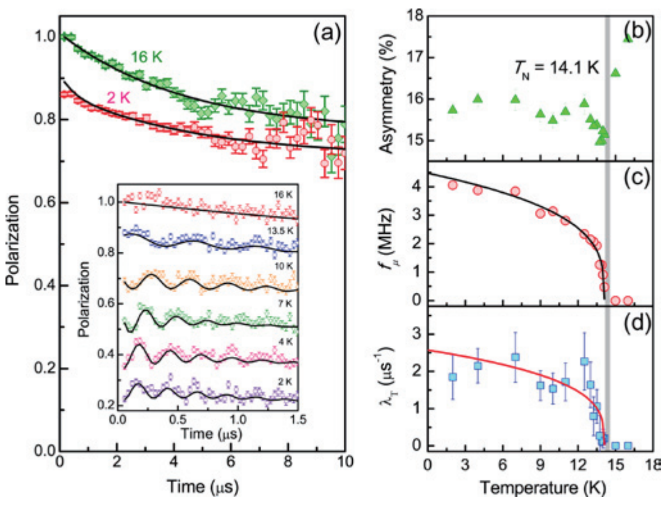

Fig. 1. (a) Representative data of the muon polarization of Ba_2CuTeO_6 measured above and below T_N. The solid lines are fits described in the text. The inset zooms the early-time behavior at various temperatures. The spectra are vertically shifted. (b),(c),(d) The asymmetry, the muon spin precession frequency f_μ, and the transverse relaxation rate λ_T as a function of temperature. The vertical bar indicates the onset of magnetic ordering at T_N =14.1 K.

The time decay of the muon spin polarization $P(t)$ at temperatures above and below T_N is shown in Fig. 1(a). Upon cooling towards T_N, we observe muon-spin precession together with a drop in the early-time asymmetry [see the inset of Fig. 1(a)], confirming the development of static local magnetic fields at the muon stopping sites. The polarization curves can be well described by the sum of an exponentially relaxing cosine function and a simple exponential function:

$$P(t)=(1-\alpha)\exp(-\lambda_L t)+\alpha\exp(-\lambda_T t)\cos(2\pi f_\mu t+\phi),$$

where the two terms represent muons polarized transverse and parallel to the local magnetic fields. The temperature dependence of the asymmetry, the muon-spin precession frequency f_μ, and the transverse relaxation rate λ_T is plotted in Fig. 1(b)-(d). All μSR parameters display distinct changes at T_N. The initial asymmetry drops rapidly on cooling to T_N. The missing asymmetry is ascribed to an unresolved precession signal within the pulsed muon beam time window.

$f_\mu(T)$, corresponding to the magnetic order parameter, is fitted to the phenomenological form $f_\mu(T)= f_0(1-(T/T_N))^\beta$, f_0=4.3 MHz is the frequency at T=0 K and β=0.29(1) is the critical exponent. The obtained critical exponent is not much different from the value β=0.365, expected for the 3D Heisenberg model. T_N =14.1 K is slightly lower than the transition temperature of 15 K determined from the uniform susceptibility. The temperature dependence of $\lambda_T(T)$ can be also modeled with the same order-parameter fit as plotted in Fig. 1(d). Taken together, a ground state of Ba_2CuTeO_6 is characterized by a conventional antiferromagnetic order, while having persisting spin fluctuations in the ordered state.

In this report, we have presented a combined study of ZF-μSR measurements on the coupled two-leg spin ladder Ba_2CuTeO_6. We observe unambiguously an oscillating signal in the ZF-μSR time spectra, suggesting that Ba_2CuTeO_6 lies close to a quantum critical point from a magnetically ordered side.

References

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