Giant Suppression of Phononic Heat Transport in a Quantum Magnet BiCu$_2$PO$_6$

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Introduction

Recently frustrated ladder-like arrangements have been realized in BiCu$_2$PO$_6$. Thermodynamic measurements on polycrystalline samples reveal that the magnetic excitation spectrum of BiCu$_2$PO$_6$ is gapped with $\Delta \sim 32$ K [1] and the recent high magnetic field measurements on the single crystals have revealed a cascade of phase transitions due to strong spin-orbit and frustrated couplings [2]. These results indicate that BiCu$_2$PO$_6$ is a good candidate for studying the thermal properties under high magnetic field around and above 30 T.[3].

Experimental

The standard steady-state method with two-thermometers and one heater is employed to measure temperature-dependent thermal conductivity ($\kappa(T)$) of BiCu$_2$PO$_6$ single crystals under high magnetic field at Cell 8 in NHMFL.

Results and Discussion

Figure 1 shows that as $H$ approaches $H_c$, the dip features in $\kappa(T)$ systematically shift toward lower temperatures, resulting in very small $\kappa$ at low temperature regions. In particular, the suppression is maximized near the critical magnetic field where the spin gap is closed and the magnetic long-range order appears. Reduction of the energy gap at the high magnetic fields will increase the transition rate between the ground state and excited states, and makes it possible to scatter more phonons. By considering the resonance scattering of the phonon into the relaxation rate equation, we could quantitatively reproduce the $\kappa(T)$ along the $a$ axis.

Conclusions

We have observed a giant suppression of $\kappa$ near the field-induced quantum critical point in BiCu$_2$PO$_6$, of which microscopic origins involve strong resonant and non-resonant scatterings of phononic heat carriers with the spin degree of freedom. Our work also points to an interesting possibility of using the quantum magnet as a field-tunable thermal insulator at high field regions.

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References


Fig.1 Experimental $\kappa_a$ and $\kappa_b$ of BiCu$_2$PO$_6$ single crystals at $\mu_0H \leq 30$ T (symbols) and a comparison with the transport theory for $\mu_0H \leq 20$ T (solid lines). The dashed lines represent $\kappa_a$ and $\kappa_b$ calculations with a minimum $\Delta_{-1}(H) \approx 0$, which represents the lowest limit of predicted $\kappa$ from the theory.