Pressure-induced quantum phase transition and magnetic excitations in the spin gap system $KCuCl_3$

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Gapped quantum spin systems provide an opportunity for correlating condensed matter physics with particle physics [1-3]. One intriguing feature is an experimental observation of the massive Higgs mode separately from the massless Nambu-Goldstone mode [4,5]. The Higgs mode is a collective mode of amplitude oscillations of order parameters. To confirm the Higgs mode, the ordered moment is required to shrink in the absence of the applied field, as realized in the pressure-induced ordered phase.

$KCuCl_3$ is a three-dimensionally coupled spin dimer system having a gapped ground state with an excitation gap of 2.67 meV [6]. The lowest magnetic excitation occurs at $\boldsymbol{Q}$ = (0, 0, 1) and its equivalent reciprocal points. Applying hydrostatic pressure, $KCuCl_3$ undergoes a pressure-induced quantum phase transition to the antiferromagnetically ordered state at the critical pressure $P_c \approx 0.82$ GPa [7]. In the vicinity of P_c, interesting quantum phenomena, including the Higgs mode, are expected to be observed.

In the present study, we measured magnetic excitations of $KCuCl_3$ using the triple-axis spectrometer HER (C1-1) installed at JRR-3 in JAEA, Tokai. The inelastic neutron scattering measurement was performed at 1.5 K under high pressures at 0.5 GPa ($< P_c$) and 0.8 GPa ($\sim P_c$). A $KCuCl_3$ single crystal was set in the Teflon cell, which was installed in the piston cylinder pressure apparatus. Deuterated glycerin was used as a pressure medium. The constant-$\boldsymbol{Q}$ energy scan profiles were collected in the a^*–c^* plane.

Figure 1 shows the constant-$\boldsymbol{Q}$ energy scans for $\boldsymbol{Q}$ along (h, 0, 1) with h = 0 and -0.25 measured at P = 0.5 GPa. Arrows denote one singlet-triplet excitation. This result indicates the softening of the excitation mode, consistent with the previous work [7].

As to the constant-Q energy scans obtained at 0.8 GPa, on the other hand, no obvious excitation peak was confirmed for the measured $\boldsymbol{Q}$-ranges. This could be because the system is in the vicinity of P_c, where the scattering intensity is typically weakened compared to the case for $P \ll P_c$.

For future work, we plan to perform similar experiments at 0.8 GPa using a longer scan time to increase the statistics.

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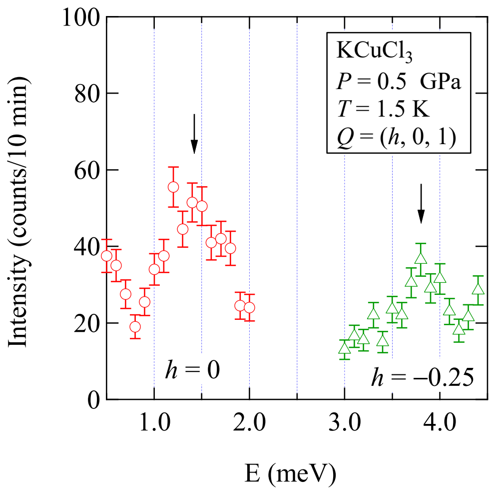

Fig. 1. Constant-$\boldsymbol{Q}$ energy scan profile for (h, 0, 1) with h = 0 and -0.25 in $KCuCl_3$ measured at T = 1.5 K and P = 0.5 GPa.