Spinon Rashba splitting on the quantum spin chain

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Rashba splitting is known as the splitting of electron bands on the surface of metallic materials because of the spatial inversion breaking. Its microscopic origin is spin-orbit coupling, which shifts a pair of the band coupled by time-reversal symmetry to the opposite *q* directions. In this analogy, we can expect the Rashba-type splitting of spinon bands in spin-1/2 quantum spin chains. The key is a uniform Dzyaloshinskii-Moriya (DM) vector along the chain, which shifts the up and down spinon bands to the opposite *q* direction under a magnetic field [1]. Although high field ESR experiments have suggested the splitting on the quantum spin chain Cs_2CuCl_4 [2], its direct observation has not been performed so far. Inelastic neutron scattering experiments should be helpful to directly confirm the splitting.

$Ca_3ReO_5Cl_2$ is the spin-1/2 chain compound with uniform DM interactions [3], where the spin chain is formed along the *b* direction. The one-dimensional characters were confirmed from inelastic neutron scattering experiments by using AMATERAS [4]. In addition, the low-energy part of the spinon continuum shows a *positive* shift from K = 0.5 r.l.u., suggesting the influence of the uniform DM interactions.

To observe the signature of spinon analog of Rashba splitting, we have performed single crystal neutron scattering experiments using triple axis spectrometer C1-1 HER in the JRR-3 reactor. Totally 1.6 g of single crystalline samples were coaligned with setting *HK*0 as a scattering plane. ^{3}He refrigerator was used to cool down to 0.3 K. Scattered neutron energy E_f was fixed to 4.223 meV. Pyrolytic graphite 002 reflections were used for monochromating and analyzing neutrons. The analyzer was set in a both horizontally and vertically focusing condition to increase counting efficiency.

Constant energy scans at 0.3 K and 2.6 K are compared in Fig. 1. The observed broad peak corresponds to the low-energy part of the spinon continuum, which is shifted to the *negative* direction from K = 0.5 r.l.u.. Constant wavevector scans (Figure 2) also show larger intensities at 0 0.47 0 than those of 0 0.53 0, supporting the negative shift. The difference between the two experiments may be explained by the different H range; while the H of the constant E scans in the C1-1 experiments was 0, AMATERAS experiments were performed at roughly H ~0.5 r.l.u. (for K ~ 0.5 r.l.u. and ΔE ~ 0.6 meV) assuming that H dependence is weak. The difference indicates that the incommensurate magnetic order with q = (0 ,0.46, 0) influences the low-energy excitations even at 2.6 K, which is more than twice of the transition temperature (1.1 K)

[1] S. Gangadharaiah et al., PRB **78**, 054436 (2008). [2] K. Y. Povarov et al., PRL **107**, 037204 (2011). [3] D. Hirai et al., JPSJ, **88**, 044708 (2019). [4] K. Nawa et al., PRResearch **2**, 043121 (2020).

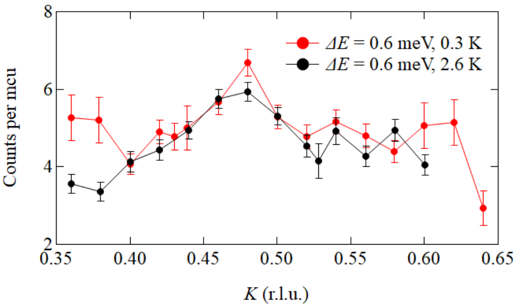

Fig. 1. Constant energy scans collected at 0.3 K (red) and 2.6 K (black).

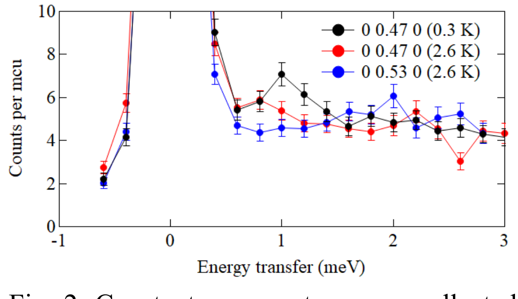

Fig. 2. Constant wavevector scans collected at 0.3 K (black) and 2.6 K (red and blue).