Thermal Hall Effect and Quantum Oscillations of Spin-Liquids: Detecting Spinon Related Fermi Surface

M. Yamashita (University of Tokyo); D. Watanabe, S. Kasahara, T. Shibauchi (Kyoto University); Y. Matsuda (Kyoto University); Luis Balicas (NHMFL)

Introduction

The quest for the ground state of a quantum-spin-liquid (QSL) state has been a long-standing issue in condensed matter physics since P. W. Anderson's proposal for the Resonating Valence Bond state in 1973. There have been many theoretical proposals about the ground state of QSLs, including exotic phenomena such as novel spin excitations with a Fermi surface coupled to an artificial gauge field. However, the nature of QSLs had been discussed only theoretically with a lack of materials. Thus the discovery of $EtMe_3Sb[Pd(dmit)_2]_2$ with an ideal two dimensional triangular lattice, and the first realization of an uniform QSL state has spurred a great deal of interest.

Recently, from the thermal transport measurements in $EtMe_3Sb[Pd(dmit)_2]_2$, we have shown that the spin excitations remain gapless and can transfer heat nearly ballistically [1,2]. This newly discovered excitation found by us could correspond to the first demonstration of the presence of spinons in a 2D spin system. In one-dimensional spins, studies of spinons have now been well established. On the other hand, spinons in 2D spin systems remain elusive. Theoretically, it has been pointed out that spinons in a 2D QSL form a Fermi surface, like electrons in metals, and could show highly exotic phenomena under high fields, such as a thermal Hall-effect [3] and quantum-oscillations associated with the spinon Fermi surface [4], in analogy to the Hall effect of charged particles and quantum oscillations in conventional metals. Therefore, the experiments under high magnetic fields, which have not been performed in this organic compound, is extremely important, because they may be the "smoking guns" proving the existence of a spinon Fermi surface, which can be a breakthrough in the studies of novel elementary excitations in strongly correlated electronic systems. We have already tried to detect the thermal Hall conductivity κ_{xy} at Kyoto University down to 230 mK, but we did not detect discernible Hall angle (κ_{xy}/κ_{xx}) up to 10 T [2]. We have also tried to detect quantum oscillations by measuring the magnetic torque up to 32 Tesla at Grenoble High Field Lab [5], but we did not detect oscillations, partly because we could not have enough machine time to test multiple samples.

Fig.1: Thermal-Hall measurement cell.

Experimental

In this experiment we tried to detect the thermal Hall conductivity at cell 8 using the resistive 35 T magnet and the 3He cryostat. We have developed a thermal-Hall cell (Fig.1) which was to be installed in the 3He-System C Cryostat. Prior to the experiment in NHMFL, the cell was calibrated at Kyoto University. At the NHMFL, we successfully installed the cell to the 3He-System C Cryostat, however, a leak in the 3He-System C Cryostat occurred and prevented us from continuing the planned experiment.

We switched our purpose to observe quantum oscillations of a Topological-Kondo-insulator candidate SmB_6 and of a QSL candidate κ-H_3(Cat-EDT-TTF)$_2$. We installed these samples to a top-loading 3He cryostat. Although the magnet time left was short, we were able to measure the resistivity and the Hall conductivity of SmB_6 and the magnetic torque of κ-H_3(Cat-EDT-TTF)$_2$ at 0.5 K for a few field sweeps to 35 T. Unfortunately, no discernible oscillations were observed in these measurements (Fig.2). Further magnet time will be necessary to optimize signal conditions and to find the best field angle to confirm the presence or absence of quantum oscillations in these materials.

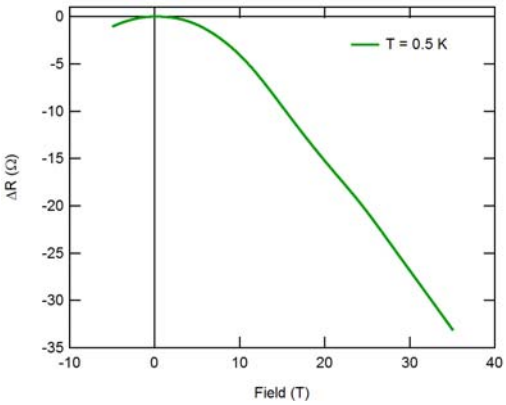

Fig. 2: Field dependence of resistance of SmB_6 at 0.5 K.

References

[1] M. Yamashita et al., Nature Physics **5**, 44-47 (2009).
[2] M. Yamashita et al., Science **328**, 1246 (2010).
[3] H. Katsura, N. Nagaosa and P.A. Lee, Phys. Rev. Lett. **104**, 066403 (2010).
[4] O. I. Motrunich, Phys. Rev. B **73**, 155115 (2006).
[5] D. Watanabe et al., Nature Communications **3**, 1090 (2012).