Magnetic structure analysis of antiferromagnets with large anomalous Hall effect

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In ferromagnets, electric current generally induces transverse Hall voltage in proportion to magnetization (anomalous Hall effect), and it is frequently used for electrical readout of the up and down spin states. While these properties are usually not expected in antiferromagnets, recent theoretical studies predicted that collinear antiferromagnetic order with non-symmorphic crystal structure can often induce large spontaneous Hall effect even without net magnetization or external magnetic field[1]. This phenomenon, often termed "crystal Hall effect", can potentially be used for the efficient electrical readout of the antiferromagnetic states, but its experimental verification has long been elusive due to the lack of appropriate materials hosting such exotic magnetism.

In this study, we focused on a antiferromagnetic metal $Mn_{11}Ge_8$ with orthorhombic crystal structure (*Pnma*), which has recently been found to host large spontaneous Hall effect despite their vanishingly small magnetization. This compound also hosts a series of metamagnetic transition as a function of temperature. To identify the magnetic structure in each phase, we performed the neutron scattering experiments for the $Mn_{11}Ge_8$ single crystal at 5G PONTA beamline in JRR-3.

Figure 1 indicates the temperature dependence of integrated intensity and wave number q of the (q, 1, 0) magnetic reflection. In the Phase I (275 K > T > 155 K), the magnetic modulation vector is identified as (0, 0, 0), indicating that the magnetic unit cell is identical with the crystallographic unit cell. In the Phase II (144 K > T >125 K), the (0, 0, 0) modulation component still exists, but additional spin components with incommensurate magnetic modulation vector (0.20, 0, 0) emerges. In the Phase III (125 K > T), the aforementioned reflections disappear and another components characterized by incommensurate magnetic modulation vector (0.18, 0, 0) emerges. Since the spontaneous Hall effect is observed in Phase I and II, the (0, 0, 0) modulation component should be responsible for the time-reversal symmetry breaking and associated Hall signal.

At this stage, the detailed magnetic structure in Phase II and III has not been established. This compound is considered as a candidate of high temperature "altermagnet" with unique spin split electronic structure[2], and further investigation of its unconventional properties associated with time-reversal symmetry breaking would be interesting.

[1] L. Smejkal *et al*., Sci. Adv. **6**, 8809 (2020).
[2] I. Mazin *et al*., PNAS 118, 2108924118 (2021).

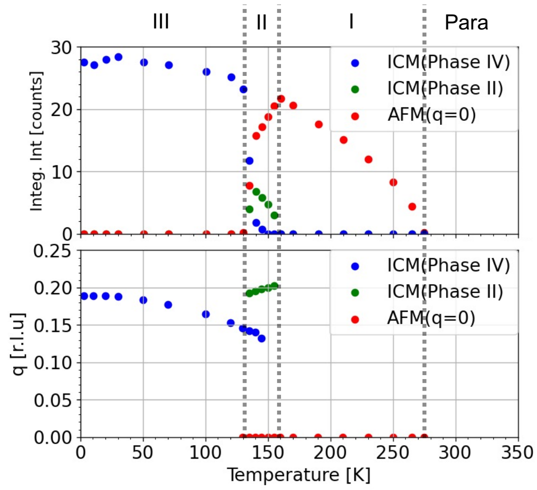

Fig. 1. Temperature dependence of (a)integrated intensity and (b) wave number q of the (q, 1, 0) magnetic reflection, measured for the single crystalline sample of $Mn_{11}Ge_8$.