Magnetic neutron diffraction experiments on $CoNb_3S_6$

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The transport of charge and entropy through metallic magnets is highly entangled with their magnetic order. In particular, the motion of electrons in such conductors occurs under the influence of an 'emergent' vector potential $\boldsymbol{A}_{\mathrm{em}}$, the Berry connection, which describes the effect of the twisting of the spin as a particle moves in a magnetic solid [1]. Various complex magnetic orders – noncoplanar antiferromagnets and ferromagnets, as well as long-period spin-vortex (skyrmion) structures – require a physical description including $\boldsymbol{A}_{\mathrm{em}}$.

Recently, a new class of antiferromagnets with layered structure and complex, canted magnetic order has been proposed as $Co(Nb,Ta)_3S_6$, where magnetic moments form an "all-in-all-out" (AIAO) pattern on two tetrahedra in the magnetic unit cell. A large spontaneous Hall effect appears in zero magnetic field, despite nearly zero net magnetization (Fig. 1; Refs. [2,3]). When considering a single layer of the structure, the magnetic sublattice of Co^{2+} ions forms an undistorted triangular lattice: on this triangular lattice, the magnetic texture corresponds to a twisted 'four-sublattice' order discussed, e.g., in Ref. [4].

The magnetic order of $CoTa_3S_6$ has been conclusively established by neutron diffraction over a wide region of momentum space at beamline SENJU (J-PARC) paired with polarized neutron scattering at PONTA-5G [2]. A competing research paper generally confirms the main results [3]. For $CoNb_3S_6$, the sister compound with weaker spin-orbit interactions, only polarized neutron scattering has been reported [2]. However, a full refinement of the magnetic structure, based on a large number of reflections, remains an open challenge. Our recent work on thermoelectric properties of $CoNb_3S_6$ [5] rests on the crucial assumption of this AIAO magnetic state, and the lack of a neutron scattering dataset evidencing AIAO order in $CoNb_3S_6$ has been pointed out to us.

We have prepared a single crystal of $CoNb_3S_6$ and carried out single crystal neutron diffraction at beamline PONTA-5G with the aim of refining the noncoplanar magnetic structure in this material. The experiments in the *H0L* and *HHL* scattering planes have been completed and the data is now being processed.

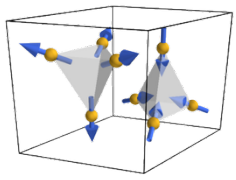

Fig. 1. Noncoplanar magnetic order proposed for $CoNb_3S_6$. Figure adapted from Ref. [5].

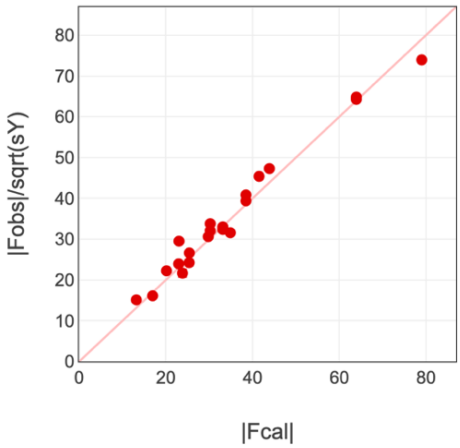

Fig. 2. Refinement of nuclear scattering intensity obtained for $CoNb_3S_6$ at beamline PONTA-5G. R = 5.8%; s_Y is a scaling factor.

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[3] P. Park *et al.*, Nat. Commun. **14**, 8346 (2023)
[4] Y. Akagi & Y. Motome, J. Phys. Soc. Jpn. **79**, 083711 (2010)
[5] N.D. Khanh, R. Yamada, M. Hirschberger *et al.*, Nat. Commun. **16**, 2654 (2025)