

Experimental report

11/01/2024

Proposal: 4-02-622

Council: 10/2022

Title: Orbital-loop-current-induced magnetic structure in a kagome superconductor

Research area: Physics

This proposal is a new proposal

Main proposer: Jun ZHAO

Experimental team: Hongliang WO

Yiqing GU

Helen WALKER

Qisi WANG

Local contacts: Mechthild ENDERLE

Ursula Bengaard HANSEN

Samples: CsV3Sb5

RbV3Sb5

Instrument	Requested days	Allocated days	From	To
ORIENTEXPRESS	1	1	18/06/2023	19/06/2023
IN20	4	7	19/06/2023	26/06/2023

Abstract:

The charge-density-wave (CDW) order in the recently highly-topical kagome superconductor AV3Sb5 (A=K, Rb, Cs) is suggested to be unconventional in nature. Intriguingly, a chiral flux phase consisting of orbital loop current was proposed theoretically, supported by the experimental observation of field-tunable charge chirality and spontaneous time reversal symmetry breaking. Nevertheless, the orbital magnetic structure induced by the loop current is yet to be determined. We thereby propose to study the orbital magnetic order and its interplay with CDW transition in RbV3Sb5 using uniaxial polarization analysis, which was previously adopted to be an effective method uncovering the orbital loop current in the pseudo-gap state of cuprate superconductors. The success of this experiment will provide crucial information on the unusual loop current state, shedding lights on the structure and microscopic origin of the exotic CDW order in AV3Sb5.

Experiment report for 4-02-622

Scientific Background

The recently discovered kagome superconductors AV_3Sb_5 ($A = K, Rb, Cs$) (Fig. 1(a)) [1] attract substantial and immediate interest due to their non-trivial band topology and diverse symmetry breaking states, including charge density wave (CDW), electronic nematicity and superconductivity [2,3]. Increasing results have suggested the CDW order to be unconventional in nature. Scanning tunneling microscopy studies have revealed a field-tunable charge chirality in all three compounds [2], accompanied by substantial anomalous Hall effect in the absence of local magnetism [4]. A chiral flux phase consisting of orbital loop current was thereby proposed by independent theoretical works (Fig. 1(b)) [5,6]. Indeed, evidence of spontaneous time reversal symmetry breaking (TRSB) has been revealed by muon spectroscopy [7-9] and magneto-optic Kerr effect measurements [10], lending support to the proposal of orbital loop current. Yet, the orbital magnetic structure induced by the loop current has not been experimentally established.

Polarized elastic neutron scattering is an effective method to detect weak magnetic moments, which has been utilized to uncover the orbital loop current in the pseudo-gap state of cuprate superconductors [11,12]. A similar methodology can be applied to AV_3Sb_5 to determine the exotic magnetic order in the chiral flux phase. Note that the TRSB state in RbV_3Sb_5 exhibits a relatively strong internal field strength among this material class, as indicated by the muon spectroscopy experiments [7-9]. This compound thus constitutes the most promising candidate to elucidate the orbital loop current state.

Experiment Results

High-quality RbV_3Sb_5 single crystals (Fig. 2(a)) have been prepared by our collaborator H. C. Lei [13]. A sharp CDW transition at ~ 102 K can be observed in dc susceptibility, resistivity and heat capacity measurements (Fig. 2 (b-d)). The superconducting transition is found at 0.92 K (see ref. [13]).

In this experiment, two pieces of RbV_3Sb_5 single crystals, both roughly in dimension of $9\text{mm} \times 9\text{mm} \times 0.3\text{mm}$, were aligned in (H, H, L) and $(H, 0, L)$ scattering plane respectively (Fig. 2(a)). Helium-3 polarization apparatus (Pastis) was equipped to measure the signals in all six polarization channels, including three non-spin-flip channels and the corresponding spin-flip channels. The feasibility of such methodology was first confirmed by observation of the super-lattice peak resulting from the $2 \times 2 \times 2$ CDW order (Fig. 3). This is followed by searching for orbital-loop-current order induced magnetic Bragg peak at potential wave-vectors. The data is now under analysis, trying to extract the extreme weak signals from background, flipping ratio decay and transmission rate correction.

References

- [1] Ortiz *et al.*, [Phys. Rev. Mater. 3, 094407 \(2019\)](#)
- [2] Neupert *et al.*, [Nat. Phys. 18, 137 \(2022\)](#)

- [3] Nie *et al.*, [Nature](#) **604**, 59 (2022)
 [4] Yang *et al.*, [Sci. Adv.](#) **6**, eabb6003 (2020)
 [5] Feng *et al.*, [Sci. Bull.](#) **66**, 1384 (2021)
 [6] Denner *et al.*, [PRL](#) **127**, 217601 (2021)
 [7] Mielke *et al.*, [Nature](#) **602**, 245 (2022)
 [8] Guguchia *et al.*, [arXiv: 2202.07713](#) (2022)
 [9] Li *et al.*, [arXiv: 2107.10714](#) (2021)
 [10] Xu *et al.*, [arXiv: 2204.10116](#) (2022)
 [11] Fauqué *et al.*, [PRL](#) **96**, 197001 (2006)
 [12] Li *et al.*, [Nature](#) **455**, 372 (2008)
 [13] Yin *et al.*, [Chin. Phys. Lett.](#) **38**, 037403 (2021)

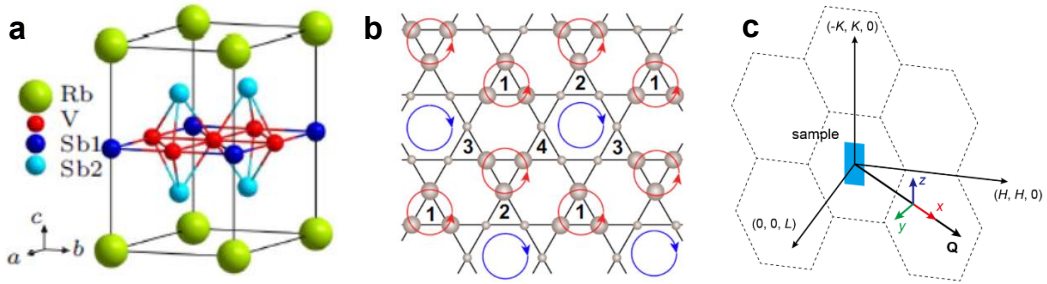


Fig. 1 **(a)** Schematic diagram of the crystalline structure of RbV_3Sb_5 [13]. **(b)** The two-dimensional pattern of orbital loop current in chiral flux phase proposed by ref. [5]. **(c)** Illustration of the configuration of proposed polarization experiment. The scattering plane is (H, H, L) . x, y and z correspond to the polarization directions in the conventional polarization coordinates.

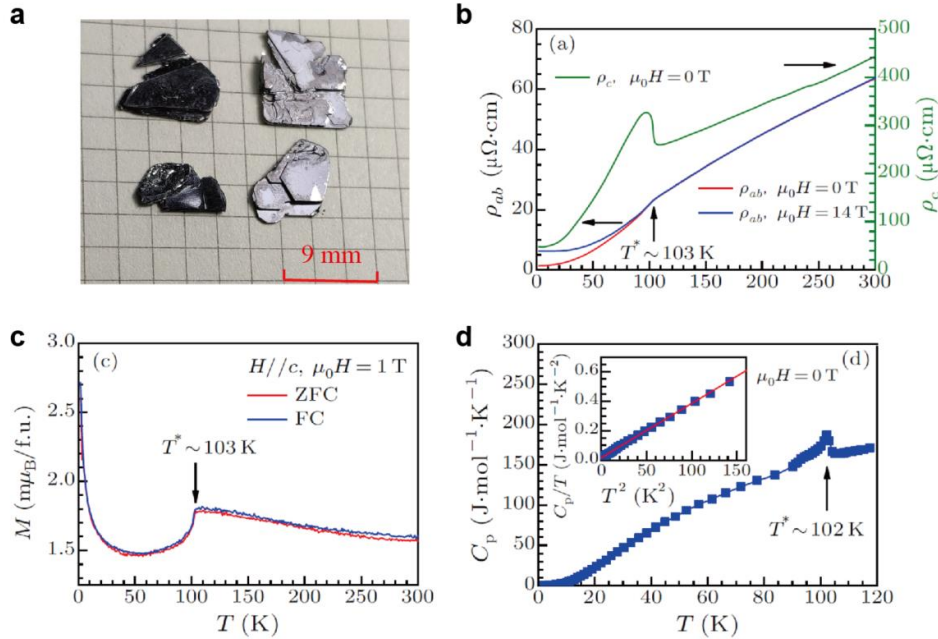


Fig. 2 **(a)** Photo of our high-quality RbV_3Sb_5 single crystals. **(b-d)** The resistivity, dc susceptibility and heat capacity measurements in RbV_3Sb_5 , demonstrating a CDW transition at ~ 102 K. (b-d) are from ref. [13].

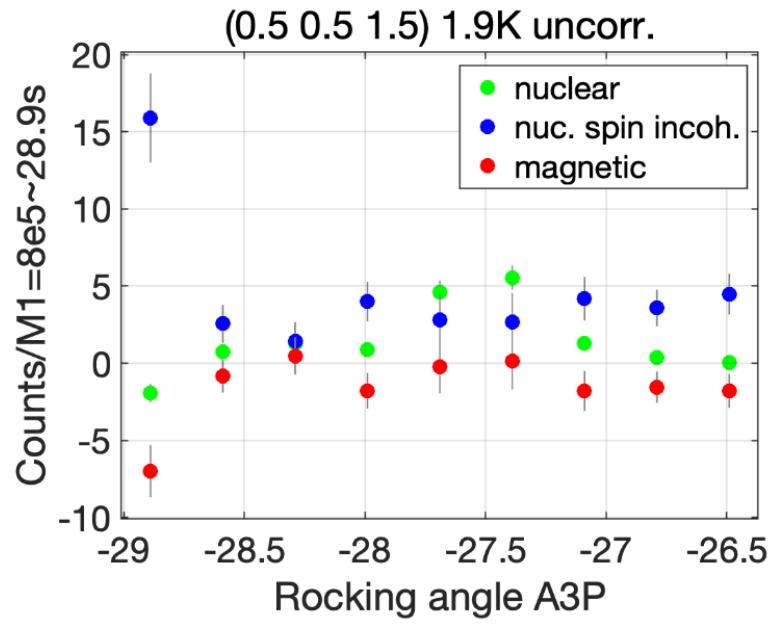


Fig. 3 A super-lattice peak was found at (0.5, 0.5, 1.5) (green dot), the signal disappeared at 120 K (not shown) suggesting its CDW origin.