Experimental report

12/09/2022

Proposal: **5-42-467** **Council:** 4/2017

Title: Chiral Effects on the Vortex Lattice in UPt3

Research area: Physics

This proposal is a new proposal

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Samples: UPt3

Instrument	Requested days	Allocated days	From	To
D11	4	0		
D33	4	3	15/07/2019	18/07/2019
D22	4	0		

Abstract:

The heavy fermion material UPt3 may justly be considered a paradigm for unconventional superconductivity and it remains the best established case of a a bulk, odd-parity, spin triplet superconductor. However, key questions remain unanswered concerning the order parameter of UPt3 in the three different superconducting phases.

Here we focus on the vortex lattice (VL) in the so-called B-phase (low-temperature/low-field) and how this will be affected by a possible broken time-reversal symmetry. Our recent SANS measurements show a clear indication of a chiral effect on the VL in the B-phase that depends sensitively on the field/temperature history. We propose to continue these measurements and definitively establish the precise connections between the VL structure and a chiral state.

Chiral effects on the vortex lattice in UPt_3

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Introduction

Topological properties of materials are of fundamental as well as practical importance. Of particular interest are unconventional superconductors that break time-reversal symmetry. We have used vortices to probe the superconducting state in ultraclean crystals of UPt_3 using small-angle neutron scattering. Our results demonstrate that the vortices possess an internal degree of freedom in one of its three superconducting phases, providing direct evidence for bulk broken time-reversal symmetry [1].

We also found that the vortex lattice (VL) in UPt_3 undergoes a gradual disordering as a function of time due to ^{235}U fission that temporarily heats regions of the sample above T_c [2]. Upon re-cooling, the vortices remain in a quenched disordered state. An ordered VL can be re-formed by applying a small-amplitude field oscillation, indicating that the fission does not cause significant radiation damage to the UPt_3 crystals.

Evidence for broken time-reversal symmetry

Measurements were performed on VLs prepared using two different field histories, both at base temperature of the used dilution refrigerator (50-65 mK). For a field reduction the applied field was first increased into the time-reversal symmetric C phase, and then reduced to the measurement field (H_m) within the B pase without changing the polarity. For a field reversal the field was decreased into the Meissner state with the chirality determined by the initial polarity of the field in the C phase, and then further decreased through zero such that H_m had the opposite polarity of the initial field.

The principal results, demonstrating that the superconducting B phase in UPt_3 possess an internal degree of freedom, is shown in Fig. 1. This shows a clear difference in the splitting angle between oppositely rotated VL domains for the two different field histories.

The structure of the order parameter in the vortex core depends sensitively on the symmetry of the parent superconducting state in the host material. We interpret the different VL splitting angles for the different field histories as being due to different vortex core configurations, corresponding to the phase winding of the vortex core being either parallel or antiparallel to the global phase winding. Here the former is fixed by the magnetic field direction upon entering the B phase while the latter is determined by the direction of the applied field.

A more extensive treatment of the SANS results demonstrating broken time-reversal symmetry is given in Ref. 1.

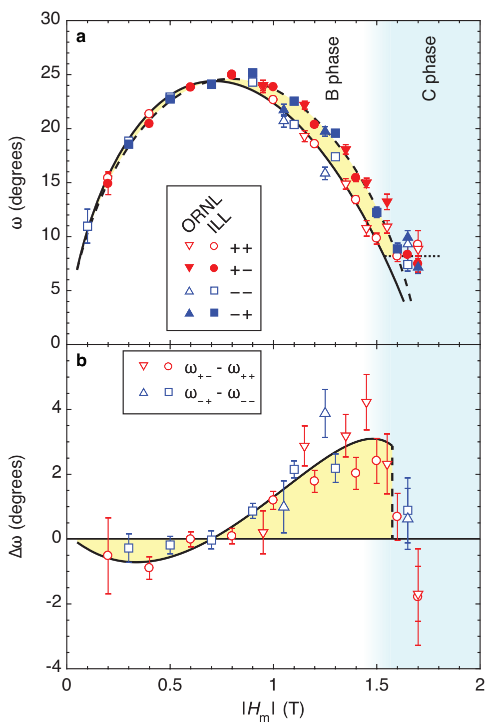

Fig. 1 Field dependence VL configuration diffraction versus applied magnetic field. (a) Splitting angle determined from the SANS diffraction patterns. (b) Difference in the splitting angle for VLs following a field-reduction (++,−−) and a field-reversal (+−,−+). From Ref. 1.

Reversible ordering and disordering of the vortex lattice

The ability to manipulate the vortices experimentally is essential to the study of vortex matter. We have demonstrated a novel approach to structural studies of vortex matter whereby fission-induced quenched disorder can be introduced in UPt_3 locally without permanently affecting the studied crystal. Here, the VL undergoes a gradual disordering on a time scale of tens of minutes as it is subjected to a beam of cold neutrons, as shown in Fig 2(a).

The disordering is due to local heating events caused by neutron-induced fission of ^{235}U, which leaves an increasing fraction of the sample occupied by a disordered vortex configuration. While the system does not spontaneously reorder once the local heating has been dissipated, it is possible to reanneal the VL by the application of a damped field oscillation.

To quantify the disordering, measurements of the VL intensity as a function of neutron exposure were performed for a range of magnetic fields. Figure 2(b) shows the disordering rates versus magnetic field for the two different UPt_3 samples studied. The direct proportionality to the applied field indicates that the disordering rate is governed by the collective properties of the vortex matter. Furthermore, the sample with the greater vortex pinning (ZR8) shows a greater resilience to disordering, as disruptions to the VL can less easily propagate away from the volume directly affection by the individual fission events.

A more extensive treatment of the SANS results showing the reversible ordering and disordering of the VL is given in Ref. 2.

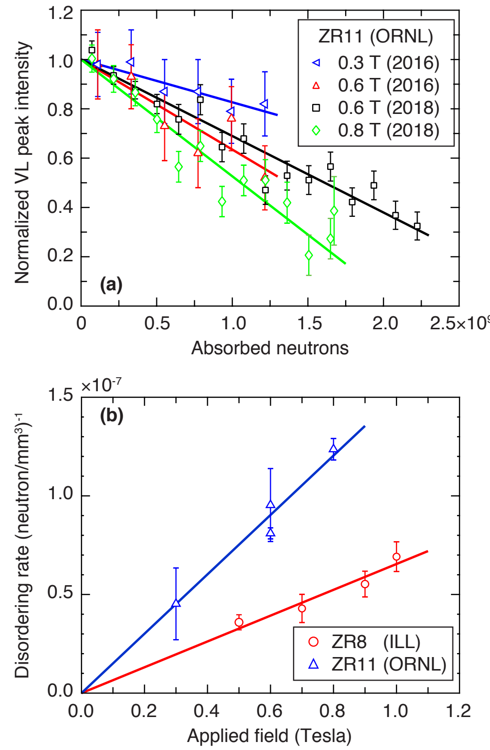

Fig. 2 (a) VL scattering rate vs absorbed neutrons/area. (b) Disordering rate per unit volume versus applied magnetic field. From Ref. 2.

References

1. K. E. Avers *et al*., Nat. Phys. **16**, 531-535 (2020).
2. K. E. Avers *et al*., Phys. Rev. B **105**, 184512 (2022).