Experimental report

06/09/2022

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Council: 4/2020

Title: Activated behavior of a first-order vortex lattice transition

Research area: Physics

This proposal is a new proposal

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Samples: YNi2B2C w/11B

Instrument	Requested days	Allocated days	From	To
D33	3	1	09/07/2021	10/07/2021

Abstract:

Vortices in type-II superconductors present a conceptually simple two-dimensional model system to examine problems such as structure formation and transformation at the mesoscopic scale, metastable states, and non-equilibrium kinetics. We will explore metastability in connection with vortex lattice (VL) transitions. Previous studies for continuous (second order) transitions revealed an activated behavior, when the VL was driven towards the equilibrium state by successive applications of ac field cycles. Moreover, the activation barrier increased as the transition towards the equilibrium state progresses, equivalent to an aging of the VL. Here we propose to expand these measurements to discontinuous (first order) VL transitions.

Activated behavior of a first-order vortex lattice transition

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Background

To fully understand the structural properties of vortex matter, it is important to also study metastable phases associated with both discontinuous (first order) and continuous (second order) phase transitions. Previously we have studied the transition kinetics and the activated behavior extensively for the continuous vortex lattice (VL) rotation transitions in MgB_2 [1,2].

In the current experiment, we performed exploratory SANS studies of VL metastability in YNi_2B_2C. This material is known to harbor a discontinuous structural VL phase transition between the low-hex and high-hex phases [3,4]. The VL phase diagram for YNi_2B_2C is shown in Fig. 1.

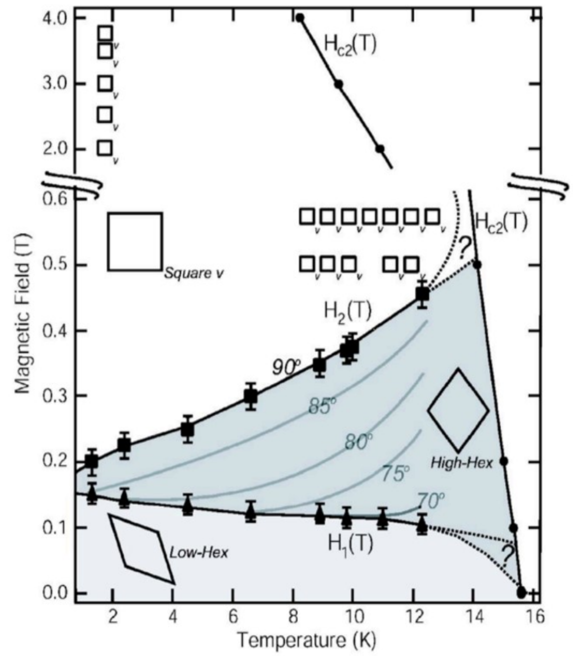

Fig. 1 VL phase diagram for YNi_2B_2C. The discontinuous VL phase transition is denoted $H_1(T)$. From Ref. [4].

Preparing a metastable VL

Initial measurements were performed to confirm the high-hex/low-hex phase boundary, denoted by $H_1(T)$ in Fig. 1, by performing a temperature sweep at 0.1 T. Before each imaging of the VL a damped field oscillation (2% of the applied field) was performed to erase any hysteric effects, making the sample's prior path in phase space irrelevant.

It was then explored to which degree it is possible to prepare a metastable VL in the high-hex phase by supercooling across $H_1(T)$. Figure 2(a) shows a VL diffraction pattern obtained by first applying a damped field oscillation at 14.5 K, and then cooling the sample to 2 K in a constant field of 90 mT. Here scattering from both high-hex and low-hex domains are present. Applying a damped field oscillation at 2 K results in a purely low-hex phase as seen in Fig. 2(b). Here, intensity along the diagonals, corresponding to the high-hex phase, is notably reduced. This is seen more clearly in Fig. 2(c) which shows the difference between the two field histories. Here clear peaks on the diagonals corresponding to the high-hex phase are observed, indicated by the sector boxes.

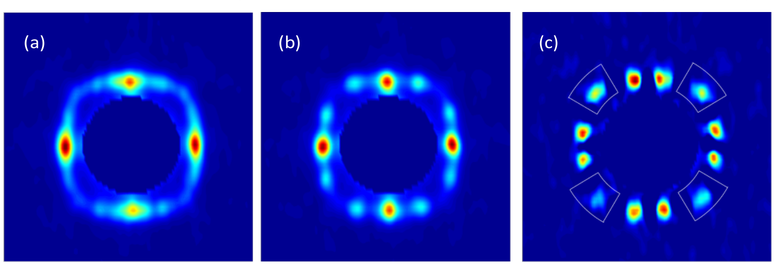

Fig. 2 VL diffraction patterns obtained at 90 mT and 2 K following different VL preparations. (a) Mixed high-hex/low-hex phase following a field cooling from 14.5 K. (b) Low-hex phase obtained after applying a damped oscillating field. (c) Subtraction of panels (a) and (b).

The results in Fig. 2 show that although some metastable domains persist following the field cooling it is not possible to obtain a purely metastable high-hex phase. Additional measurements were carried out at 90 mT and 115 mT and with starting temperatures from 12.0 K to 14.5 K. Although hints of mixed high-hex and low-hex states for a few combinations, the largest degree of metastability was observed for the parameters in Fig. 2.

Varying the preparation of the high-hex phase

We also explored whether varying the preparation of the high-hex phase affects the degree of metastability. Figure 3 shows the comparison of VL diffraction patterns where the initial high-hex phase was prepared by a damped field oscillation at 14.5 K or by field cooling from the normal state.

From the subtraction shown in Fig. 3(c) is it clear that while there is a small difference in the high-hex intensity in the sector boxes, the effect is small.

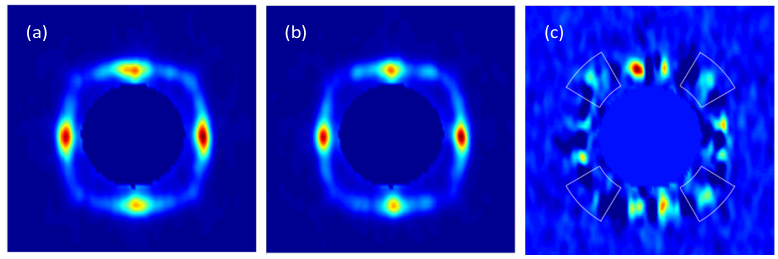

Fig. 3 Comparison of the field cooled mixed high-hex/low-state at 2 K and 90 mT following different preparations of the high-hex state. (a) High-hex state prepared by applying a damped field oscillation at 14.5 K. (b) High-hex state prepared by field cooling from the normal state. (c) Subtraction of panels (a) and (b).

Field oscillation driven reduction of high-hex VL domains

In the case of MgB_2, the VL can be driven from the metastable state to the equilibrium state by the successive applications of small-amplitude field oscillations [1,2]. We explored whether the same is the case for YNi_2B_2C. Figure 4 shows the intensity due to the supercooled high-hex VL domains versus the number of damped field oscillation cycles applied. Each cycle had an initial amplitude of 2% of the applied field. The initial state (0 cycles) was obtained by field cooling from 14.5 K and 90 mT as described above. The data shows an ~10% reduction in the intensity of the high-hex VL domains.

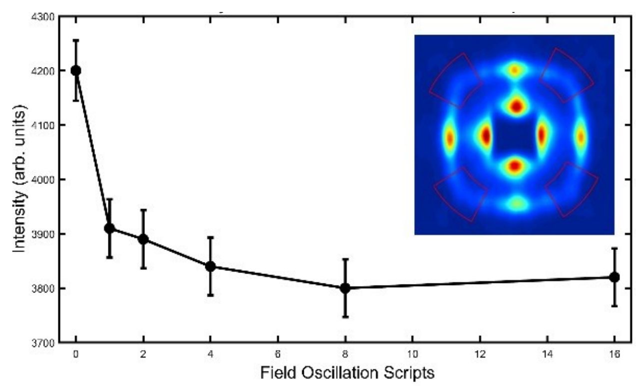

Fig. 4 Intensities of the high-hex VL intensity within the sector boxes shown in the inset versus the number of applied field oscillations.

Conclusion

Our measurements show that it is possible to obtain a limited degree of VL metastability in YNi_2B_2C in connection with the high-hex to low-hex transition. This unfortunately precludes studies of the activated behavior associated with the metastable to equilibrium VL transition in this material.

References

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4. C. D. Dewhurst, S. J. Levett, and D. M. Paul, Phys. Rev. B **72**, 014542 (2005).