Experimental Report

13/01/2014

Proposal: **5-42-349** **Council:** 10/2012

Title: Jamming, glassy dynamics and critical slowing down for the metastableVL phases in MgB2

This proposal is a new proposal

Researh Area: Physics

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Samples: Mg(11)B2

Instrument	Req. Days	All. Days	From	To
D11	4	3	25/03/2013	28/03/2013

Abstract:

Recently vortex lattice (VL) metastabilty was observed in MgB2. In this material the hexagonal ground state VL rotates continuously as function of field and temperature, between being aligned along the two high symmetry directions in the basal plane. Metastable VL phases can be created by heating or cooling the sample across the onset of the reorientation transition. Once a metastable VL is present, a transition to the ground state can be triggered by a small-amplitude oscillation of the magnetic field.

We propose a SANS experiment to investigate the mechanism responsible for the metastability as well as the dynamics of the transition to the ground state. Field-cycling measurements have shown that the transition to ground state is not due to vortex pinning, but due to jamming of VL domains. Preliminary measurements using a transverse AC magnetic field to drive the VL to the ground state showed a power law dependence on the number of cycles applied independent of frequency. This suggests a scaling behavior in further support of VL domain jamming.

We propose to search for evidence for a critical slowing down of the metastable to ground state dynamics common in jammed systems.

Experiment Summary 5-42-349: Jamming, glassy dynamics and critical slowing down for the metastable VL phases in MgB_2

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INTRODUCTION

Recently vortex lattice (VL) metastabilty was observed in MgB_2. In this material the hexagonal ground state VL rotates continuously as function of field and temperature, between the two high symmetry directions in the basal plane. Metastable VL phases can be created by heating or cooling the sample across the onset of the reorientation transition. Once a metastable VL is present, a transition to the ground state can be triggered by a small-amplitude oscillation of the magnetic field.

Previous measurements of the change in vortex density with applied field showed the transition to ground state was not due to vortex pinning [1]. Preliminary measurements performed at ILL using a transverse AC magnetic field to drive the VL from the metastable to the ground state displayed a power law dependence on the number of cycles applied independent of frequency. This suggests a scaling behavior, similar to other jammed systems. In this small-angle neutron scattering experiment, we investigated the mechanism responsible for metastability, the dynamics of the transition to the ground state, and searched for evidence of dynamics common in jammed systems.

EXPERIMENT DETAILS

Small-angle neutron scattering (SANS) experiments were performed on the D11 instrument at Institut Laue-Langevin using a standard configuration with the applied magnetic field parallel to the incoming neutron beam [2]. An orange cryostat with extended tail cooled the sample to 1.5 K and was used in conjunction with a 1 T electromagnet.

The sample, the primary MgB_2 single crystal used by the group, was located in a coil capable of generating an AC magnetic field of a few hundred Gauss oriented perpendicular to the applied field. The coil, built by Charles Dewhurst, was attached to the end of a sample stick for a standard orange cryostat, Fig. 1. A function generator connected to a power supply provided the current necessary to drive the coil.

There are three possible ground state vortex lattice orientations for MgB_2, as shown in Fig. 2. The metastable (MS) vortex lattice (VL) was prepared by warming to 18 K, performing a small damped field oscillation of the applied field around 0.5 T, and then cooling across the F-L phase boundary to 2 K. Once the MS VL state was verified, an AC field of a given amplitude and frequency was applied for a number of cycles. Every application of

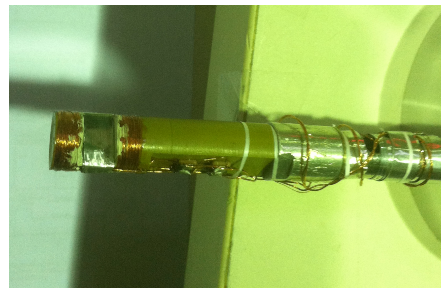


FIG. 1: The coils provided an AC filed perpendicular to the applied field. The MgB_2 sample was located between the two coils

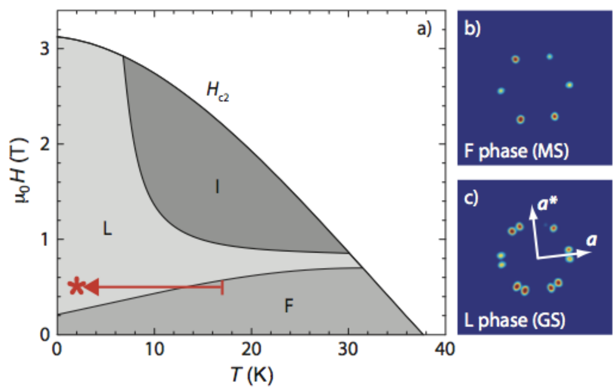


FIG. 2: (a) The ground state VL phase diagram consists of three hexagonal phases, F, L, and I. The VL for the F and I phases are oriented along the crystaline a and a* axes and have 6 peaks in the diffraction pattern (b). The L phase has domains of hexagonally oriented vortices rotated away from the direction of high symmetry. Because of degeneracy in the rotation of the VL, there are 12 peaks in the diffraction pattern instead of the usual 6 (C). Field cooling at 0.5 T across the F-L phase boundary to 2 K , as shown by the red arrow, creates a MS VL [3].

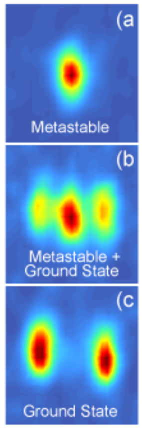


FIG. 3: The evolution of the VL from MS to the GS. (a) The as prepared MS state diffraction pattern. (b) After 120 cycles of a 25 G, 250 Hz AC field both the MS and GS peaks are visible. (c) After 10,000 cycles, only the GS peaks are visible.

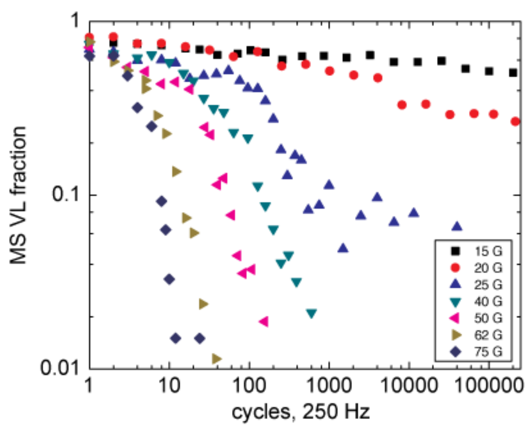


FIG. 4: Evolution of VL from MS to GS in MgB_2. Relative intensity of the MS and GS VL Bragg peaks measured as a small amplitude AC magnetic field with frequency 250 Hz was applied for a varying number of cycles.

the AC field drove part of the VL into the GS, creating a coexistence of MS and GS VL domains. A diffraction image was taken at a single Bragg scattering angle after each application of the AC field, and the results showed the decreasing intensity of the MS diffraction peaks and the increasing intensity of the GS peak, as see in Fig. 3. The azimuthal intensity distribution of the diffraction peaks were fit using gaussians to determine the area under the curves. The peak intensities were used to find the change in the relative intensities of the MS state, the calculation of which is described in Rastovski *et al.* [1]. This process was repeated for an increasing number of cycles. The data for different amplitude and frequency AC field oscillations are shown in Fig. 4, 5.

Finally, we attempted to map out the MS and GS of

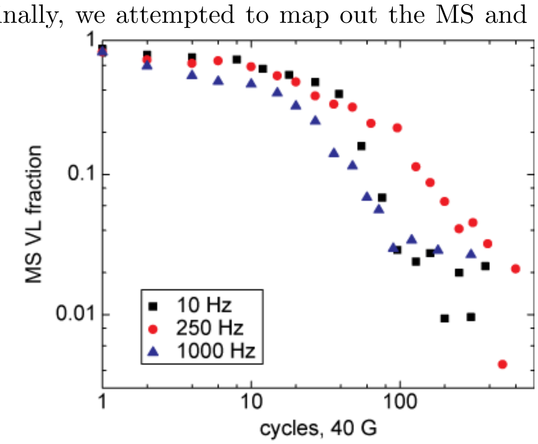


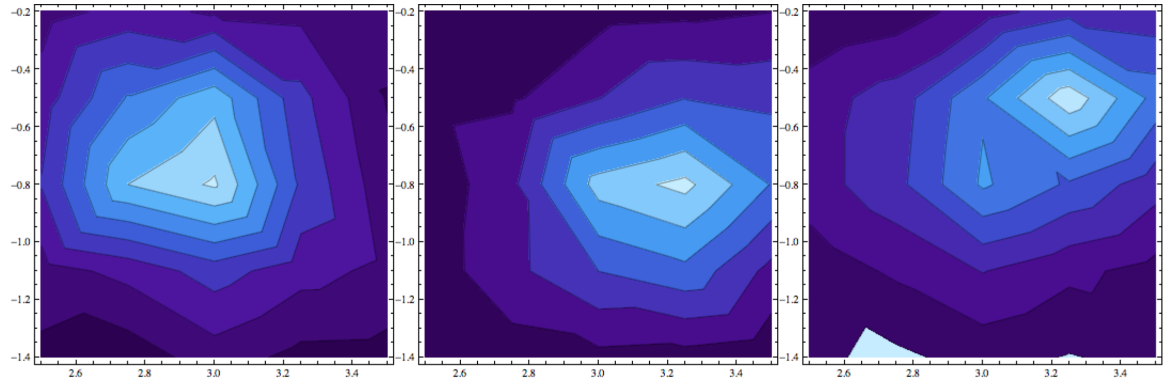
FIG. 5: Evolution of VL from MS to GS for AC field oscillations of different frequencies. The amplitude of the AC field was 40 G in each instance.

the VL in real space using a 0.5 mm sample aperture while scanning in steps of 0.25 mm in the x-direction and 0.2 mm in the y-direction. A plot of the intensities for each diffraction peak show the boundaries of the sample and indicate that the MS and GS domains are not evenly distributed over the sample, Fig. 6.

CONCLUSION

In conclusion, we used SANS to measure the MS VL transition to the GS through the application of an AC magnetic field oriented perpendicular to the applied field. The transition was observed for several amplitudes and frequencies. A low resolution real space image of the state of the VL was generated using a scanning SANS technique. These results are very promising, but fully exploring the large phase space will require more beam time.

[1] Rastovski *et al.*, Phys. Rev. Lett. **111**, 107002 (2013).
[2] M. R. Eskildsen, Front Phys **6**, 398 (2011).
[3] P. Das *et al.*, Phys. Rev. Lett. **108**, 167001 (2012).



(a) (b) (c)

FIG. 6: Raster scan to produce real space image of VL domain distribution in cts/std mon. (a) Left GS peak intensity. (b) MS peak intensity. (c) Right GS peak intensity.