Experimental Report

07/10/2013

Proposal: **5-42-320** **Council:** 10/2011

Title: Jamming in the vortex lattice of MgB2

This proposal is a new proposal

Researh Area: Physics

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Samples: MgB2

Instrument	Req. Days	All. Days	From	To
D11	4	3	26/10/2012	29/10/2012

Abstract:

The vortex lattice (VL) in the two-band superconductor MgB2 shows a large degree of metastabilty. Here the hexagonal 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. For metastable VLs a transition to the ground state can be triggered by vortex motion induced e.g. by a small change of the magnetic field. Here we propose a SANS experiment to investigate the mechanism responsible for the VL metastability as well as the dynamics of the transition to the ground state. Careful field-cycling measurements shows that the transition to ground state is inconsistent with a simple Bean model, but that it can possibly be understood as a jamming phenomenon. Preliminary measurements using a transverse AC magnetic field to drive the VL to the ground state have shown a power law dependence on the number of cycles applied independent of frequency. This suggests a scaling behavior in further support of jamming as the mechanism responsible for the VL metastability. We propose to extend these measurements.

Experiment Summary for 5-42-320: Jamming in the vortex lattice of MgB_2

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INTRODUCTION

Recently, we discovered an unprecedented degree of vortex lattice (VL) metastability in MgB_2 [1]. In MgB_2, a triangular VL that undergoes a rotation transition is observed for H ∥ c. At both endpoints of this transition, the VL is aligned with a high symmetry direction in the hexagonal crystalline basal plane. As seen in Fig. 1, the F-phase is aligned with the crystalline a-axis. In the L-phase, the VL is rotated away from the a-axis, leading to two degenerate domain orientations and consequently 12 peaks in the diffraction pattern. Once the rotation reaches 30°, the VL is now aligned along the a*-axis and labeled the I-phase. The metastable VL configurations in MgB_2 are obtained when crossing either the F-L or the L-I transitions by cooling or heating in a constant field.

The goal of this experiment was to further investigate how the vortex lattice of MgB_2 transitions from the metastable (MS) state to the ground state (GS). During a previous experiment, we discovered that the MS VL could be partially driven to the GS by reducing the applied field by a small amount, creating a coexistence of MS and GS VL in the sample. In this experiment, we applied a driving force to the MS VL in the form of a small, AC magnetic field perpendicular to the applied field, with the result that the MS VL was gradual driven to the GS. The coexistence of the MS and GS VL was measured using small angle neutron scattering technique with a tightly collimated neutron beam. By making detailed observations of the MS to GS VL transition, we hope to determine the mechanism behind the robust metastability in MgB_2.

EXPERIMENT DETAILS

The experiment was performed on the D11 beam line at ILL using the standard SANS configuration. The sample, the primary MgB_2 single crystal used by the group, was located in a coil capable of generating a vertical AC magnetic field of a few hundred Gauss. The coil was attached to the end of a sample stick for a standard orange cryomagnet, capable of reaching temperatures as low as 2 K and horizontal magnetic fields up to 2 T.

After optimizing the beam, a MS VL was prepared by cooling across the F-L phase boundary in a field of 0.5 T (see Fig. 1). Diffraction images of the transitioning VL were measured at 2 K after an AC magnetic field with amplitude of 25 G and frequencies of 50, 100, or 250 Hz was applied for an increasing number of cycles. The relative fraction of MS VL was calculated in the method described in Ref. [2] and preliminary results are show in Fig. 2.

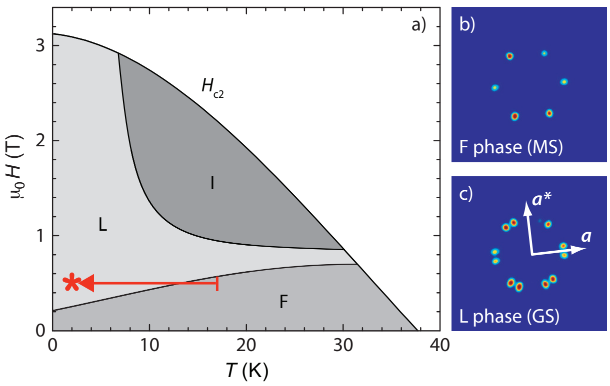

FIG. 1: Creating the MS VL in MgB_2. (a)The three phases of the ground state VL phase diagram are F, L, and I. (b)The VL for the F phase is oriented along the a-axis. (c) The 12 diffraction peaks seen in the L phase result from degenerate domains of hexagonally oriented vortices rotated away from the direction of high symmetry. Field cooling at 0.5 T across the F-L phase boundary to 2 K creates a MS VL, as indicated by the red arrow and star [2].

Similar scans were performed with AC field of 10 G, 20 G, and 25 G at 250 Hz, and 20 G and 50 Hz, with results summarized in Fig. 3 and Fig. 4. A similar measurement was made at 10 K with an AC field of 100 G and 250 Hz, where the MS VL transitioned to GS much closer to the phase boundary, as shown in Fig. 5.

To explore the effect of increasing amplitude, scans were performed where the frequency of the AC field was 250 Hz, and the number of cycles applied after each measurement was 4096 cycles. The amplitude of the field was steadily increased, however. This measurement was performed at 2 K and 10 K for the MS to GS transition, Fig. 6 and Fig. 7.

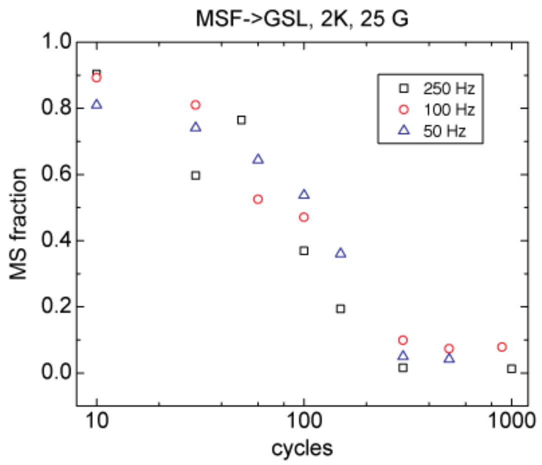

FIG. 2: AC field of 25 G and 50, 100, or 250 Hz driving the MS to GS VL transition at 2 K. After the VL was prepared in the MS F-phase, the AC magnetic field was applied for a certain number of cycles. Diffraction images after each application of the AC field yielded the fraction of MS VL present in the sample. The frequency of the AC field did not affect the number of cycles it took to transition the VL from the MS F-phase to the GS L-phase.

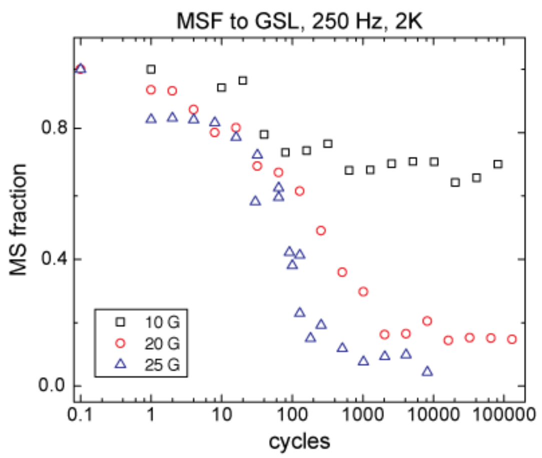

FIG. 3: AC field of 10, 20, and 25 G, and 250 Hz driving the MS to GS VL transition at 2 K. An AC field of 10 G never caused the VL to fully transition to the GS. All three amplitudes follow the same curve up to 100 cycles.

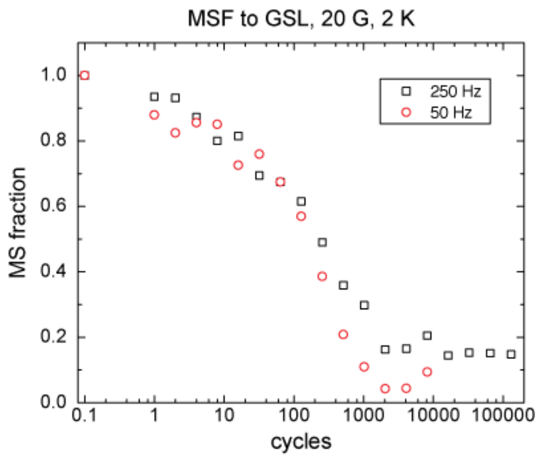

FIG. 4: AC field of 20 G, at 50 and 250 Hz driving the MS to GS VL transition at 2 K. Just as with the 25 G AC magnetic field, the 20 G AC magnetic field causes a transition to the GS that is independent of frequency.

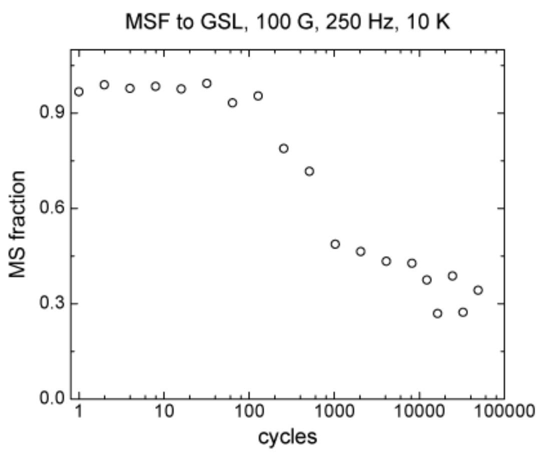

FIG. 5: AC field of 100 G and 250 Hz driving the MS to GS VL transition at 10 K. It took a significantly large amplitude AC magnetic field to drive the VL to the GS at this temperature.

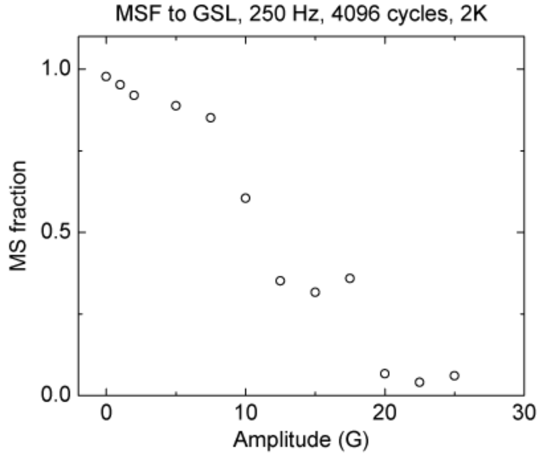

FIG. 6: The VL was prepared in the MSF state and driven to the GSL at 2 K by applying successively larger amplitude AC magnetic field pulses of 4096 cycles each. The VL transitioned to the GS at an AC field amplitude of about 20 G.

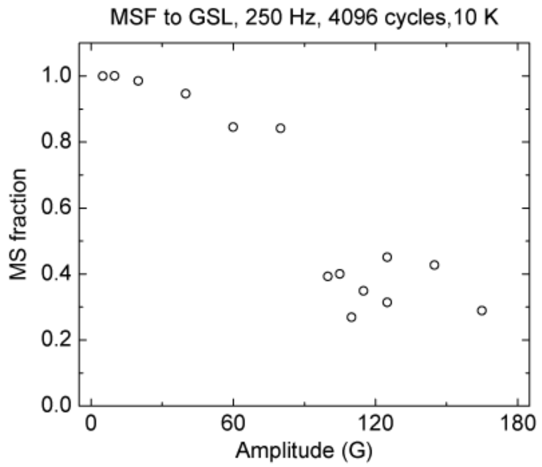

FIG. 7: The VL was prepared in the MSF state and driven to the GSL at 10 K by applying successively larger amplitude AC magnetic field pulses of 4096 cycles each. The VL stopped transitioning around 100 G when the VL was 30% in the MS state.

In conclusion, we were successfully able to obtain detailed information on the MS VL in MgB_2 as it transitioned to the GS when subjected to a driving force in the form of a small AC field perpendicular to the applied magnetic field using SANS. Preliminary analysis indicates that larger amplitude AC fields were more effective at driving the MS to GS transition, and the transition occurred independent of the frequency of the AC field. Curiously, at higher temperatures, a larger amplitude was necessary to drive the transition. Due to the large parameter space that needs to be explored, there are still many questions to answer with regard to the MS to GS transition, and more beam time is required to make a complete analysis.

[1] P. Das, C. Rastovski, T. R. O'Brien, K. J. Schlesinger, C. D. Dewhurst, L. DeBeer-Schmitt, N. D. Zhigadlo, J. Karpinski, and M. R. Eskildsen, Phys. Rev. Lett. **108**, 167001 (2012).

[2] C. Rastovski, K. J. Schlesinger, W. J. Gannon, C. D. Dewhurst, L. DeBeer-Schmitt, N. D. Zhigadlo, J. Karpinski, and M. R. Eskildsen, *et al.*, Phys. Rev. Lett. **111**, 107002 (2013).