Experimental Report

14/01/2014

Proposal: **5-42-341** **Council:** 4/2012

Title: Studies of the Vortex Lattice in Sr 2RuO4 with H || a

This proposal is a new proposal

Researh Area: Physics

Main proposer: **ESKILDSEN Morten Ring**

Experimental Team: GANNON William
ESKILDSEN Morten Ring
RASTOVSKI Catherine
KUHN Stephen

Local Contact: DEWHURST Charles

Samples: Sr2RuO4

Instrument	Req. Days	All. Days	From	To
D33	5	6	26/09/2012	01/10/2012
			15/05/2013	20/05/2013

Abstract:

Sr2RuO4 is an unconventional superconductor. While this is generally believed to have triplet pairing, this conclusion have recently been questioned [K. Machida and M. Ichioka, Phys. Rev. B 77, 184515 (2008)]. In stead is it proposed that many of the observations which were used to argue in favor of triplet pairing (e.g. specific heat) can also be explained as being due to Pauli paramagnetic effects (PPE).

Initial studies of Sr214 with the field close to the a-axis showed a signal due to the transverse field modulation giving rise to spin flip scattering which is increased dramatically above the non-spin flip scattering. Our results showed a large anisotropy with a possible field dependence. Furthermore, the scattered intensity show a non-monotonic behavior, with a maximum occurring at an angle relative to the basal plane which varies with the applied field.

Here we propose to extend our measurements to higher fields which we not available during earlier experiment performed at D22.

Experiment Summary for 5-42-341: Investigations of the Vortex Lattice of Sr214

C. Rastovski, S. J. Kuhn, and M. R. Eskildsen
Department of Physics, University of Notre Dame, Notre Dame, IN 46556

C. D. Dewhurst
Institut Laue-Langevin, 6 Rue Jules Horowitz, F-38042 Grenoble, France
(Dated: May 15 to May 21, 2013)

I. INTRODUCTION

The purpose of this experiment was to continue our study of the anisotropy of the vortex lattice (VL) of Sr_2RuO_4 with the applied field close to the crystalline basal plane. Our previous experiments at Institut Laue–Langevin (ILL) in Grenoble, France showed that Sr_2RuO_4 may behave unusually when it is close to H_{c2} or T_c.

In this experiment we had several goals. First, we wanted to fully explore the field dependence of the VL form factor on the angle of the applied magnetic field, Ω. A previous experiment found that the anisotropy (Γ) for an applied magnetic field of 0.2 T with $\Omega > 1.3$ degrees yielded a VL anisotropy larger than infinity. Our second goal was to further explore this low field, high Ω region. Our third goal was to determine the temperature dependence of the diffraction peak intensity at different Ω's.

Due to the very large anisotropy (Γ_{ac}) of Sr_2RuO_4, the VL is highly distorted, with Bragg reflections expected to lie on an ellipse with a major-to-minor axis ratio $\gamma_{VL} = \Gamma_{ac}/\left[\cos^2\Omega + (\Gamma_{ac}\sin\Omega)^2\right]^{1/2}$, where Ω is the angle at which magnetic field H has been rotated away from the basal plane. In addition, a large value of Γ_{ac} will also give rise to a substantial transverse component to the VL field modulation for field close to (but not perfectly aligned with) the basal plane as discussed in [1]. The transverse field modulation leads to spin flip (SF) scattering, in contrast to the (ordinary) longitudinal component which is non-spin flip. Because of the SF scattering, this experiment naturally lends itself to the use of a polarized neutron beam.

II. EXPERIMENTAL SET-UP

The experiment was performed on the D33 beam line at ILL using the standard SANS configuration, with the addition of polarization analysis [2]. A dilution refrigerator (DR) was inserted inside a standard orange cryomagnet allowing us to access temperatures between 0.050 and 1.3 K and fields as high as 2 T. The Sr_2RuO_4 sample, previously used by the group, was a cylindrical rod 30 mm long and 3 mm wide, with a $T_c = 1.5$ K and an upper critical field in the H$\|$a direction of 1.5 T. The a-axis of the sample was roughly aligned using the neutron camera, and final determination of the a-axis came from analysis of rocking curves (RCs).

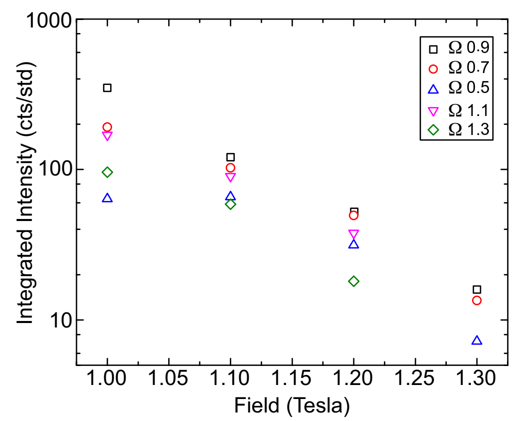

FIG. 1. The RC intensity compared to magnetic field, for several Ω. The RC intensity decreases with increasing field, as expected.

When neutrons scatter from the VL of Sr_2RuO_4, their spins change orientation by 180°, or spin-flip. Using polarized neutrons significantly improves the ratio of signal to noise in the VL diffraction images. A cell of polarized He-3, in conjunction with appropriate magnetic shielding, was used to screen neutrons with undesirable spin. The cell was still strongly polarized after 24 hours, and the following figures do not take the change in polarization of the cell into account.

Rocking curves were measured for various rotations of the magnetic field from the crystalline a axis, defined as Ω, between -1.3 and 1.3 degrees and for multiple magnetic field amplitudes. Figure 1 shows the general decrease in the rocking curve integrated intensities as magnetic field increased. Figure 2 shows how the integrated intensities change with field at various Ωs.

As described in the introduction, for $\Omega > 1.3°$, low magnetic fields yield unexpectedly large anisotropies. RC intensities were measured for both positive and negative Ω at 0.2 T and 0.05 K. These scans are shown in Fig. 3, with RC integrated intensity plotted against the absolute value of Ω. Short count times (of approximately 2 minutes per point) were enough to provide good statistics for these RC's.

RCs were measured for five different temperatures (0.05 K, 0.25 K, 0.5 K, 0.75K, and 1 K) and 0.4 T at different Ωs. Only one diffraction peak was measured at

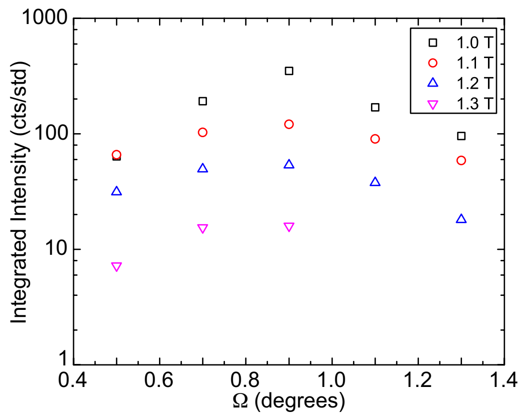

FIG. 2. The same data as Fig. 1, presented as the change in intensity based on magnetic field for varied Ω's. Intensity decreases with increasing magnetic field. Large Ω's did not have visible peaks for 1.3 T or 1.35 T. This figure is in qualitative agreement with previous results.

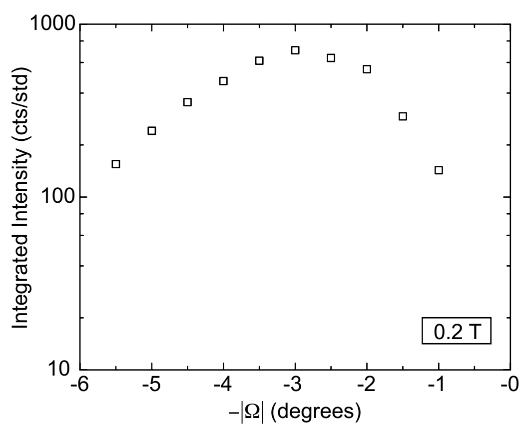

FIG. 3. The intensity of a single diffraction peak for a polarized neutron beam at 0.2 T, 0.05 K for various $-|\Omega|$.

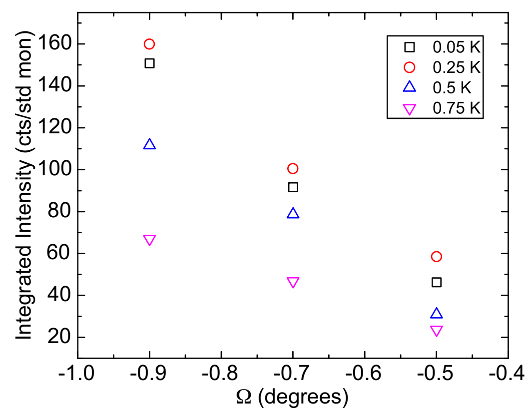

FIG. 4. The RC integrated intensities for 4 temperatures at different Ω values.

higher temperatures in order to save time, and there was no measurable signal 1 K for count times of 5 min/point. The intensity decreased both as Ω approached zero and temperature increased.

III. CONCLUSION

Data were acquired regarding each of the three initial experimental questions. RC's were studied between $\Omega = 0.5 - 1.3$ degrees and fields between $1.0 - 1.3$ T. Low field measurements were performed at 0.2 T and $\Omega > 1.3°$. RC peaks were measured at four different temperatures. Additionally, the polarization significantly reduced background, as expected; however, maintenance of the He-3 cell slowed progress. To perform a full temperature scan at 1 K or higher, more beam time will be required.

[1] P. G. Kealey et al., Phys. Rev. B **64**, 174501 (2001).
[2] M. R. Eskildsen, Front Phys **6**, 398 (2011).