Experimental report

18/02/2020

Proposal: DIR-183 **Council:** 4/2019

Title: THE NATURE OF THE SUPERCONDUCTINGSTATE IN SR2RUO4

Research area:

This proposal is a new proposal

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Samples: Sr2RuO4

Instrument	Requested days	Allocated days	From	To
IN20	7	7	14/06/2019	20/06/2019

Abstract:

EXPERIMENT DIR-183 ON IN20 IN JUNE 2019
THE NATURE OF THE SUPERCONDUCTING STATE IN Sr_2RuO_4

A. Abstract

Sr_2RuO_4, a strongly correlated oxide metal, has been considered as a solid state equivalent to superfluid ^{3}He-A [11] with time reversal symmetry breaking [10] and odd-parity order parameter since its superconducting state was discovered [12]. This was underpinned by NMR Knight shift K [9] and polarized neutron scattering (PNS) [3] measurements which observed no drop in the spin susceptibility χ_{spin} in the superconducting state. Recent ^{17}O NMR measurements with uniaxially applied strain [5] shown a small change in K and observed that previous work suffered from sample heating. Here we report a repetition of our previous PNS experiment at significantly lower magnetic field H and with higher statistics. We observe a drop of $\approx$ 34% in susceptibility χ in the superconducting state relative to the normal state for $\mathbf{H} \parallel [010]$.

B. Experimental details

PNS [7] measurements were carried out on a single crystal of Sr_2RuO_4 (C117) with dimensions of $1.5\times2\times5\text{mm}^3$ mounted in a dilution fridge with 2.5T magnet on the three-axis spectrometer IN20. To improve thermal conductivity the sample was mounted on a copper mount and directly connected by two 1mm^2 wires to the sample stick (see Fig. 1a). The critical temperature of our sample is T_c =1.47 K and the critical field $\mu_0 H_{c2}$ =1.44 T. After characterisation of the polarisation in- and outside the superconducting mixed state the analyser was removed to increase statistics. The data were collected at the (101) reflection at 60mK and 1.5K with $\mu_0 H$ from 0.5T to 2.5T with $\mathbf{H} \parallel [010]$. The data are normalised on time where the polarisation was flipped every 11 s to reduce effects from long term fluctuations of the reactor. Data sets with visible disturbances in the monitor counts are excluded. The normal state was primarily studied at 2.5 T to improve signal to background while the superconducting state χ was probed at 60 mK and 0.5 T for about 52 h or 26 h per polarisation. Correction for non-unity beam polarisation, non-linear detector and background/dark counts are included in any analysis.

C. Results

The flipping ratio R in a paramagnet is $R = I_{\uparrow\uparrow}/I_{\downarrow\downarrow} \approx 1 + 4F_M/F_N(\mathbf{Q})$ where F_M is the magnetic and F_N the nuclear structure factor. We observed non-unity flipping ratios under all applied conditions meaning Sr_2RuO_4 always has non-zero χ.

Remarkably, unlike our previous PNS measurement [3] we detected a reduced susceptibility in the superconducting state (see Fig. 1c for comparison). This is qualitatively consistent with recent ^{17}O NMR measurements on Sr_2RuO_4 which shown a small change in K between the normal and the superconducting state, for the in-plane oxygen positions [5, 8]. Notably, those oxygen sides do not contribute to the (101) reflection instead effectively only χ on the Ruthenium side is probed. We refer the differences to our previous study to density of states induced by vortices in the mixed state, a large zero field residual value and better statistics (see Fig. 1d). We are unable to make quantitative statements about the zero field residual as we are still far away from zero field limit. However, our data points towards a large residual for an isotropic gap superconductor possibly due to spin-orbit coupling or to a low residual for a (near-)nodal superconductor (see Fig. 1d). Our results are consistent with singlet superconductivity and triplet superconductivity with an in-plane **d**-vector. For further statements about triplet or singlet paring precise data near the zero field residual or close to the critical field might be of help.

D. Conclusions and publication of this work

Reduced χ_{spin} on the Ruthenium side of highly topical superconducting Sr_2RuO_4 was observed in PNS for fields applied in the ab-plane which is in disagreement with previously accepted triplet paring. The data supports singlet pairing or triplet pairing with an in-plane **d**-vector. The results of this study are submitted to Physical Review Letters [4] and will also contribute to the PhD thesis of Alexander.

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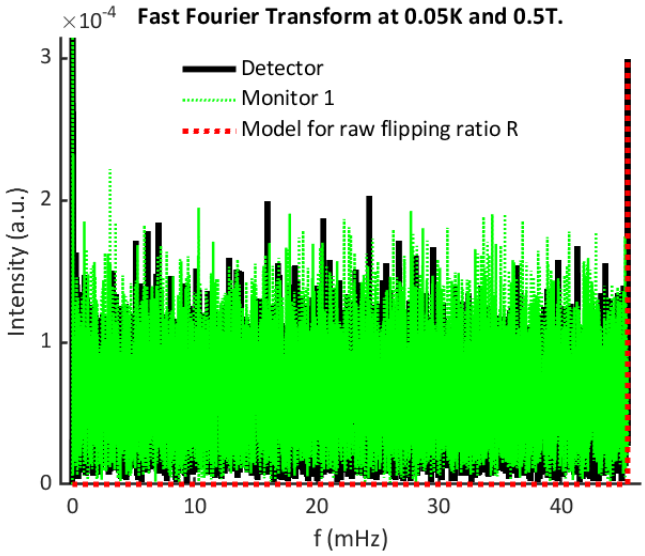
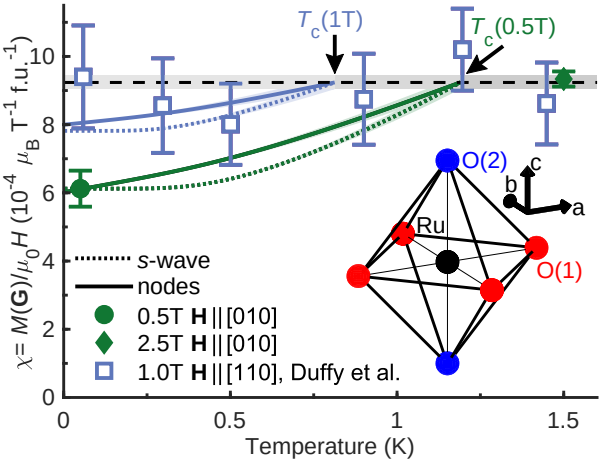
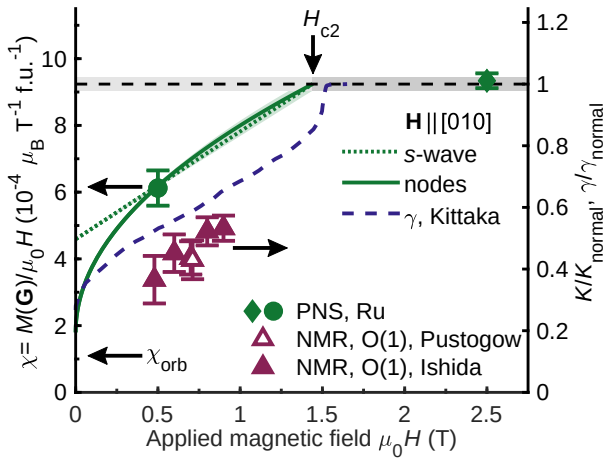
(a) Sample attached to copper post on mini-goniometer connected with two 1 mm^2 copper wires to the cryostat sample rod.



(b) The Fourier transform of detector and monitor signals for one measurement series. A signal due to the flipping ratio is visible in the detector but not the monitor channel it should therefore refer to scattering from the sample.



(c) Temperature dependence with isotropic and nodal gap model [1, 14, 15] and the data from our previous experiment [3].



(d) Field dependence at 60 mK with a 34% drop in the superconducting state, modelled for isotropic and nodal gaps [2, 13] in comparison with the linear coefficient of the specific heat γ [6] and the recent NMR Knight shift data K [5, 8].