The out-of-plane magneto-resistivity of $Sr_3Ru_2O_7$

Robin Perry [a,1], Andrew Mackenzie [b], Yoshiteru Maeno [c]

[a] *School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK*

[b] *School of Physics and Astronomy, University of St Andrews, St Andrews, Fife KY16 9SS, UK*

[c] *International Innovation Center and Department of Physics, Kyoto University, Kyoto 606-8501, Japan*

Abstract

We present measurements of the *c*-axis resistivity as a function of magnetic field for the bilayered ruthenate $Sr_3Ru_2O_7$. It has been established that this material displays itinerant electron metamagnetism. Here,we show that like our published work on the in-plane magnetoresistance, the out-of-plane magnetoresistance has features that are clearly identifiable with the metamagnetism at identical fields. However, the out-of-plane magnetoresistance appears to have a strong dependence on crystal quality, which may provide a reason for the discrepancy between our findings and those of others.

Key words:
$Sr_3Ru_2O_7$; magnetoresistance; metamagnetism;quantum critical point

The perovskite strontium ruthenate series of materials first came to prominence with the discovery of superconductivity in the two dimensional member Sr_2RuO_4 in 1994 [1]. This discovery was made possible by advances in crystal growth techniques that have allowed single crystals of impurity or residual resistivity ρ_{res} as low as $0.1\mu\Omega$cm (for the current parallel to the ruthenium oxide planes). Indeed, subsequent measurements have shown that the superconducting state is highly dependent on the level of impurities and is suppressed when ρ_{res} $\sim 1\mu\Omega$cm [2]. This and other measurements have identified Sr_2RuO_4 as a p-wave or spin triplet superconductor [3].

Here, we report out-of-plane magneto-resistivity measurements on the bilayered ruthenate $Sr_3Ru_2O_7$. $Sr_3Ru_2O_7$ has been found to be an itinerant metamagnet with a Fermi liquid ground state [4,5]. Recent low temperature measurements of the in-plane transport have provided evidence that a new type of quantum critical point (QCP) might reside in this system [6]. This type of QCP is created when a critical point that terminates a line of first order phase transitions is suppressed to near zero temperature. Such a QCP would constitute a novel type of criticality since it is not associated with a second order phase transition, and so is not connected with a symmetry-broken phase.

Here, we discuss the effects of the criticality on the magneto-transport properties of $Sr_3Ru_2O_7$. Peaks in the magnetoresistance (MR) have been observed [5,7] to $\sim$20K for the current I in the ab plane ($I \| ab$) indicating that the proximity of the system to a field induced critical point is enhancing the scattering. However, there is a difference between data published so far for $I \| ab$ and $I \| c$. For the magnetic field parallel to the ruthenium oxide planes ($B \| ab$), magnetisation measurements show that the metamagnetic field is around 5T, and a peak at this field is clearly seen the resistivity for $I \| ab$ below 20K [7,5]. At higher temperatures it disappears, and a negative MR is observed. MR data ($I \| c$) for $B \| ab$ have been reported by Liu *et al.* [6], and seem to contrast with the basic features seen for $I \| ab$. A peak in the MR was seen only below 2K, and at an applied field of 4T rather than 5T. It is not clear why changing the current direction should have such

[1] Corresponding author. Present address: Department of Physics, Kyoto University, Kyoto 606-8502, Japan. E-mail: perry@iic.kyoto-u.ac.jp

an effect so we have made measurements on the c axis magneto-resistivity to try and clarify the issue.

The crystals used in this project were grown using a floating zone technique at Kyoto University and were taken from the same growth run that produced crystals with an in-plane impurity resistivity ρ_{res}^{ab} of $2\mu\Omega$cm [8]. The measurements were made on a ^{4}He cryostat situated at Birmingham University. We used a low frequency a.c. technique with a current of 1mA. Magnetic fields of up to 12T were applied with the field orientation perpendicular to the current. The main contribution to the error on the absolute resistivity was from the measurement of the dimensions and was estimated to be around 10 percent.

The measured out-of-plane residual resistvity ρ_{res}^{c} of the three crystals A, B and C were $725\mu\Omega$cm, $870\mu\Omega$cm and $1085\mu\Omega$cm, respectively. Figure 1 shows a plot of the MR versus applied field for three crystals at three different temperatures. The peak is observed at 5T which is nearly identical to the metamagnetic field observed for $I\|ab$. The behaviour of the peak at high temperatures is also similar. The peak height decreases with increasing temperature and disappears by 20K. Above 25K the MR is negative indicating that spin related scattering is dominating over orbital scattering.

It is possible that the difference betweeen the results reported here and in ref. 7 is due to crystal quality. The residual resistivty ρ_{res}^{c} of all three crystals studied here is similar to that reported by Ikeda [4] ($\sim900\mu\Omega$cm) but lower than that of Liu's ($\sim2800\mu\Omega$cm). The data suggest that there is a dependence of $\Delta\rho/\rho(0)$ at 5T and 5K on ρ_{res}^{c}. The peak in the MR appears to be inversely proportional to the residual resistivity, so it is possible that it would be washed out altogether by ρ_{res}^{c} $\sim$3mΩcm. Above 25K agreement between our results and those of Liu *et al.* is good. Liu and co-workers measure $\Delta\rho/\rho(0)$ $\sim$-0.055 at 7T and 30K compared to our value of -0.06. The metamagnetism in $Sr_3Ru_2O_7$ is only observed below $\sim$20K [5] and our data indicates that above this temperature impurities in the system have a reduced effect on the scattering.

The nature of the impurities in this system is unclear. Both sets of crystals were grown using a floating zone technique so contamination from the growth crucible is irrelevant. However, single crystal growth of the strontium ruthenate series is complicated by the high vapour pressure of RuO_2 and the resulting concentration gradient in the melt [9]. This creates a tendency for phases of Sr_2RuO_4 and $Sr_4Ru_3O_{10}$ to form inside the single crystals. These intergrowths would be expected to be laminar in nature due to the highly two dimensional nature of the materials and could provide an explanation for the discrepancy in the $I\|c$ MR measurements since planar intergrowths would be expected to disrupt the current paths more effectively for $I\|c$ than for $I\|ab$.

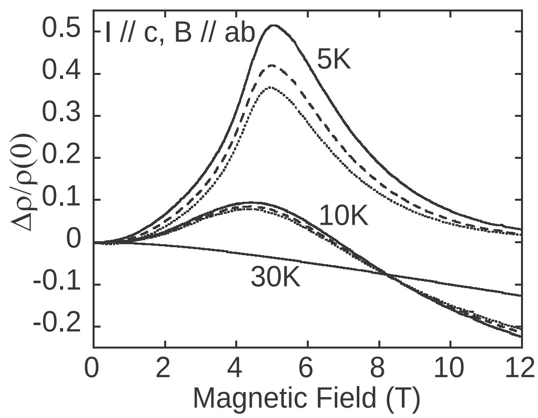

Fig. 1. The magnetoresistance of $Sr_3Ru_2O_7$ for the current I parallel to the c axis and the magnetic field parallel to the ab plane. The solid, dashed and dotted lines correspond to crystals A, B and C, respectively. $\Delta\rho/\rho(0)$ is defined as $(\rho(B)-\rho(0))/\rho(0)$.

In summary, we have performed c axis MR measurements between 5K and 30K and in magnetic fields $(B\|ab)$ up to 12T on $Sr_3Ru_2O_7$. We have found that the value of the metamagnetic critical field and temperature scale of the metamagnetism for $I\|c$ is almost identical to those for $I\|ab$ which is in disagreement with published results [7]. The possible cause for the discrepancy may be due to intergrowths in the crystals. Our data tentatively suggest that impurities in $Sr_3Ru_2O_7$ suppress the metamagnetism and support the observation that the ground states in these compounds are very sensitive to disorder.

Acknowledgements

This work was supported by the Japan Society for the Promotion of Science, the Leverhulme trust, the Royal Society and U.K.EPSRC.

References

[1] Y. Maeno *et al.*, Nature **372** (1994) 532

[2] A.P. Mackenzie *et al.*, Phys. Rev. B **54** (1996) 7452.

[3] E.M. Forgan *et al.*, J. Low Temp. Phys. **117** (1999) 1567.

[4] S. Ikeda *et al.*, Phys. Rev. B **62** (2000) R6089.

[5] R.S. Perry *et al.*, Phys. Rev. Lett. **86** (2001) 2661.

[6] S.A. Grigera *et al.*, Science **294** (2001) 332.

[7] Y. Liu *et al.*, Phys. Rev. B **63** (2001) 4435.

[8] L. Capogna *et al.*, Phys. Rev. Lett. **88** (2002) art. no. 076602.

[9] S.I. Ikeda *et al.*, Physica C **364** (2001) 376.