High Pressure de Haas-van Alphen Studies of the Layered Ruthenate Ca_2RuO_4

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Introduction

The ruthenate family of oxides is host to a remarkably diverse collection of electronic ground states. Sr_2RuO_4 for instance is believed to be a rare example of a spin triplet superconductor [1], while $Sr_3Ru_2O_7$ exhibits a metamagnetic transition that may give rise to an exotic nematic electron liquid [2]. The high purity levels of these materials have allowed extremely detailed quantum oscillation studies of the Fermi surfaces, which have proven useful in understanding the origin of novel electronic states. One member of the ruthenates that not yet been studied in this manner is the compound Ca_2RuO_4, which is a Mott insulator at ambient pressure, but can become a ferromagnetic metal under applied hydrostatic pressure [3]. Using a novel pressure cell design developed in our own lab [4,5], we aimed to fully characterize the electronic structure of the metallic phase of this compound. Of particular interest was the ability to study how the Fermi surface and electronic correlations evolve as a function of pressure as the Mott transition is approached.

Experimental

We used a ^{3}He insert with the 31T wide-bore facility in Cell 5 at the NHMFL in Tallahassee for our experiments. A two coil susceptibility measurement was used to detect quantum oscillations, with the modulation coil located inside our specially designed Cu-Be moissanite pressure cell for optimal sensitivity [4,5]. A lockin amplifier was used to measure the pickup signal, detecting on the first harmonic. The field was swept from 31 Tesla to as low as 15 Tesla at a rate of approximately 0.5 T/min. Signal to noise levels at high field were comparable to noise levels in our in-house 18 T superconducting magnet at Cambridge. We followed the temperature dependence of the oscillations from a base temperature of 300 mK to temperatures as high as 7 K.

Results and Discussion

Quantum oscillations were observed successfully in pressure cells with pressures from ranging from 14 to 32 kBar. Fig. 1 shows an example of the raw data (inset), alongside a Fourier transform (main panel). An extremely complex Fourier spectrum is observed, with roughly 12 peaks, suggesting a complicated Fermi surface. A first comparison with unpublished band structure calculations suggests that a scenario involving a reconstruction of the FS due to rotation of the RuO octahedra with accompanying splitting due to ferromagnetism and warping may account for all of the observed peaks, but a full analysis of the data is ongoing. For the easily observable peaks (ie the 3.2 kT peak in Fig. 1) the masses are quite light, $m^*/m_e \sim 1.5$.

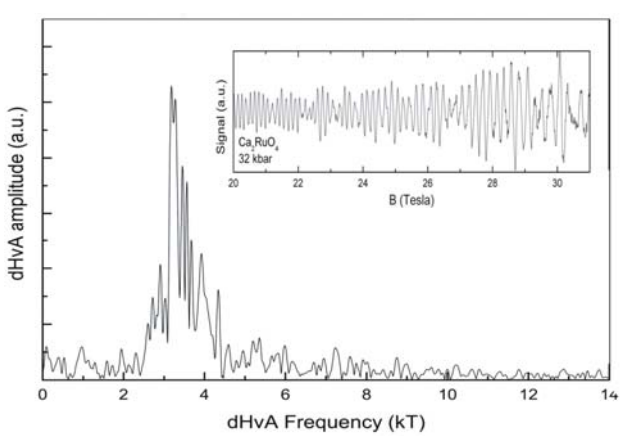

Fig. 1: dHvA ocillations in metallic Ca_2RuO_4 at T= 300mK and P = 32 kBar

Conclusions

We have succeeded in measuring quantum oscillations in the metallic state of Ca_2RuO_4 for the first time, and detailed comparison to band structure calculations are underway. The effective masses of the observed orbits are quite light, on the order of the free electron mass. They do not appear to diverge significantly as the Mott transition at low pressures is approached, and this could reflect the first order nature of the Mott transition in this material, which is accompanied by a structural transition.

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References

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