de Haas - van Alphen measurements on $CeRhIn_5$ under pressure

Donavan Hall [a,1], S. W. Tozer [a], E. C. Palm [a], T. P. Murphy [a], R. G. Goodrich [b], J. L. Sarrao [c]

[a] *1800 E. Paul Dirac Dr. Tallahassee, Florida 32311, USA*
[b] *Louisiana State University, Department of Physics, Baton Rouge, Louisiana 70803, USA*
[c] *Los Alamos National Laboratory, MST-10, Los Alamos, New Mexico 87545, USA*

Abstract

Measurements of the de Haas - van Alphen effect have been carried out on the heavy fermion anti-ferromagnet $CeRhIn_5$ at temperatures between 25 mK and 500 mK under pressure. We present some preliminary results of our measurements to track the evolution of the Fermi surface as the pressure induced superconducting transition is approached.

Key words: de Haas-van Alphen; heavy fermions; superconductivity; high pressure

1. Introduction

The dimensionality of the 115 materials, $CeRhIn_5$, $CeIrIn_5$, and $CeCoIn_5$, appears to be related to their superconducting transition temperature. The material with the highest T_c, $CeCoIn_5$, has the most 2D-like Fermi surface (FS) of the three. [1] $CeRhIn_5$ has a high T_c (∼2.1 K), but only under a pressure of ∼16 kbar. At ambient pressures, $CeRhIn_5$ is an anti-ferromagnet. The FS of $CeRhIn_5$ was the subject of one of our recent publications.[2] In order to confirm the link between the superconducting state and FS dimensionality, the FS as a function of pressure in $CeRhIn_5$ should be measured. If the FS becomes more 2D-like as the critical pressure is approached, then this will be evidence for making a connection.

In these materials it seems that superconductivity does not appear until the overlap between the *f* electron wavefunctions is sufficient to allow band-like behavior. Measurements of the FS as a function of pressure should show this increasing overlap as a change in topography. Here we present measurements up to 7.9 kbar, about half the critical pressure for $CeRhIn_5$.

2. Results

We have designed and built small pressure cells, capable of running in a dilution refrigerator and in a rotator. Measuring torque inside a pressure cell is impossible, so we have made small compensated pickup coils which fit into the cell. Each coil has four to five thousand turns. The filling factor approaches unity because we are able to situate the coil along with the sample inside the cell. A small coil is wound on the exterior of the cell to provide an ac modulation of the applied field.

We have measured the FS of $CeRhIn_5$ under several pressures. At each pressure we measure FS frequencies and their amplitude dependence as a function of temperature. From this we can extract information about how the effective mass of the quasiparticles is changing as the pressure is increased. The figures show the Fourier spectra of $CeRhIn_5$ under ∼7.9 kbar. The crystal was oriented so that the a-b axis plane is perpendicular to the applied field.

[1] E-mail:hall@magnet.fsu.edu

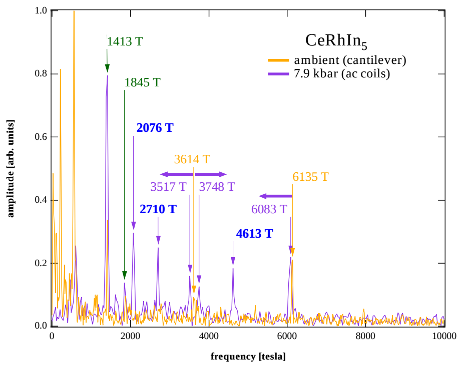

Fig. 1. The higher frequency spectrum for the sample under pressure shows the increase of amplitude of three peaks; an effect that can be attributed to improved sample/coil coupling at higher pressures.

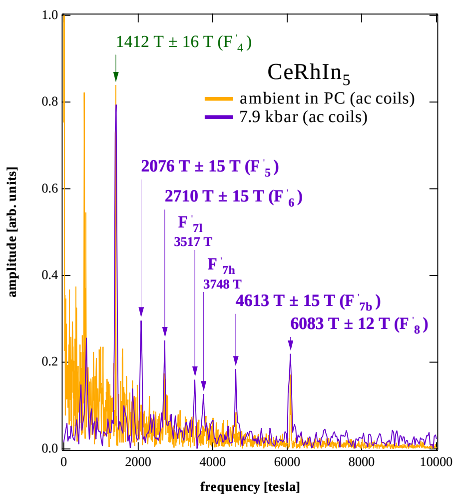

Fig. 2. Comparison of the Fourier spectra of CeRhIn$_5$ at ∼7.9 kbar and at ambient pressures (measured in the pressure cell prior to pressurization) reveals little that is suggestive of change.

3. Discussion

We show the 7.9 kbar data compared with two sets of data taken at ambient pressure. In Fig. 1 the FS at 7.9 kbar is compared with the ambient data taken with a torque cantilever (the same data reported in [2]). Because the modulation field for the ac measurements (in the pressure cell) was so small, the lowest frequencies can be ignored. Notice that the 1411 T (F_4', the designation given in Ref. [2]) and 1845 T peaks are reproduced exactly in the ambient and the pressure data sets. The 1845 T peak was not included in Ref. [2] because of its small amplitude in ambient pressure torque measurements.

The 3600 T (F_7') and 6120 T (F_8') peaks are present in both data sets; however, the F_7' appears to have split and the F_8' appears to have shifted down in frequency. Such changes could be explained as slight differences of sample alignment with respect to the applied field between the torque measurement and the pressure cell measurement. Three other frequencies, 2076 T, 2710 T, and 4613 T, emerge in the pressure data which are close to to some reported in Ref. [2] to be observed only at the lowest temperatures (25 mK).

All but the first of these frequencies are seen also in ambient pressure data taken with the sample in the pressure cell prior to pressurization as shown in Fig. 2. Thus, assuming the differences in frequency between the torque measurements and pressure cell measurements are due to differences in alignment, we can make frequency assignments that follow Ref. [2] (also shown in Fig. 2). The relative increase in amplitude with increasing pressure of these three peaks could be a result of the increase of the coupling factor between the sample and the coil as the two are compressed together.

The lack of any clear differences in the FS up to 7.9 kbar suggests that if the FS changes, then such change is not a linear function of pressure. Nor is there a compelling reason to think that it should be a linear function. Possibly, at some pressure closer the the critical pressure, the transition to f electron itinerate behavior will take place leading to more noticable changes in the FS.

4. Conclusions

The FS of CeRhIn$_5$ appears to remain topographically stable under the application of pressure up to 7.9 kbar. Additional measurements which approach the critical pressure (∼16 kbar) are of prime importance.

Acknowledgements

This work was performed at the National High Magnetic Field Laboratory, which is supported by NSF Cooperative Agreement No. DMR-9527035 and by the State of Florida. Work at Los Alamos was performed under the auspices of the U. S. Dept. of Energy.

References

[1] Donavan Hall, E.C. Palm, T.P. Murphy, S.W. Tozer, Z. Fisk, U. Alver, R.G. Goodrich, J.L. Sarrao, P.G. Pagliuso, and Takao Ebihra. *Phys. Rev. B* **64**, 212508 (2001), cond-mat/0102533

[2] Donavan Hall, E.C. Palm, T.P. Murphy, S.W. Tozer, Eliza Miller-Ricci, Lydia Peabody, Charis Quay Huei Li, U. Alver, R.G. Goodrich, J.L. Sarrao, P.G. Pagliuso, J. M. Wills, and Z.Fisk. *Phys. Rev. B* **64**, 064506 (2001), cond-mat/0011395