Evidence for an Orbital Moment in the Superconducting State of URu_2Si_2

G. Li (NHMFL), Q. Zhang (NHMFL), D. Rhodes (NHMFL), B. Zheng (NHMFL), P. Goswami (NHMFL), P. H. Tobash (LANL), F. Ronning (LANL), J. D. Thompson (LANL), E. D. Bauer (LANL), and L. Balicas (NHMFL)

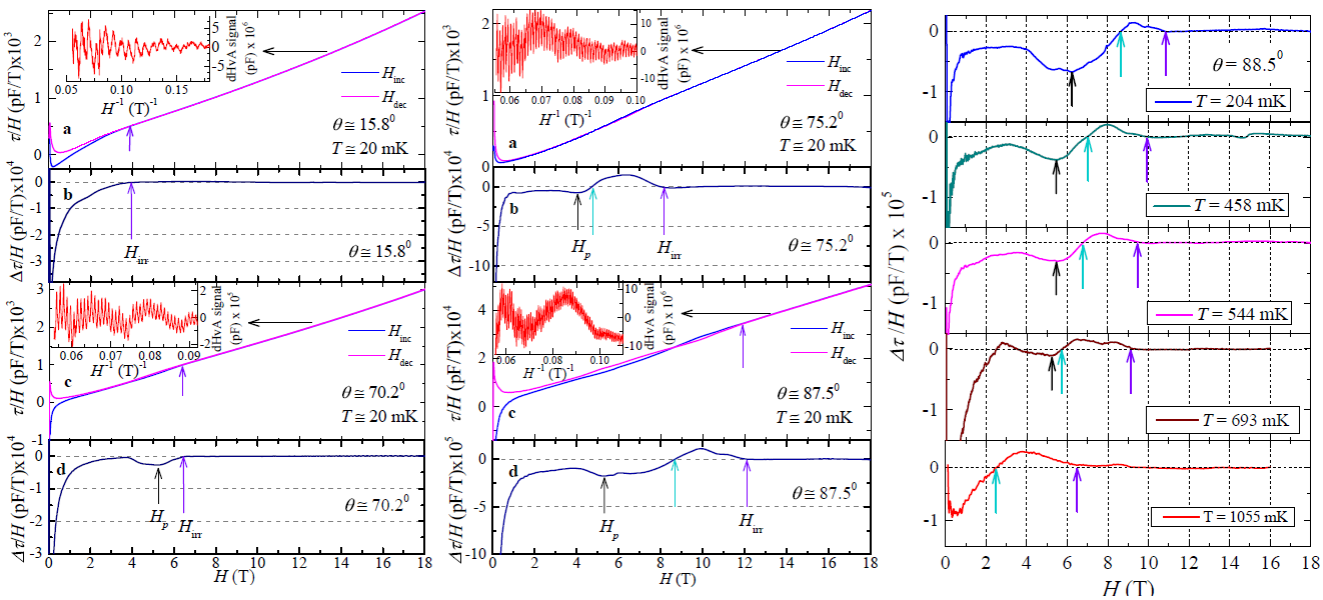
Introduction

URu_2Si_2 was suggested to be a chiral *d*-wave superconductor with a k_z ($k_x \pm ik_y$) [1] orbital component for the Cooper pair wave-function. This state breaks time-reversal symmetry due to the orbital moment associated with the pair wave-function. We performed torque magnetometry on URu_2Si_2 at high fields and very low temperatures revealing a change in the sign of the magnetic hysteresis for $H \rightarrow H_{c2}$, and for angles up to 15^0 away from the *ab*-plane [2].

Experimental

We used the superconducting magnet system SCM1 to measure magnet torque in a high quality single crystal of URu_2Si_2.

Results and Discussion



Left panel: (a) Magnetic torque τ normalized by the external magnetic field H as a function of H for a URu_2Si_2 single-crystal at a temperature T = 20 mK. The angle θ between the c-axis and the magnetic field is θ =15.8^0. Blue and magenta lines correspond to field-up and down sweeps respectively, purple arrow indicates the irreversibility field. (b) Irreversible/hysteretic component in the magnetic torque, $\Delta\tau/H$ from the traces in (a). (c) Same as in (a) but for an angle θ = 70.2^0. (d) Same as in (b) but for θ = 70.2^0. Black arrow indicates the field H_p where a minimum is observed in $\Delta\tau/H$. Insets: oscillatory component, i.e. de Haas van Alphen-effect, superimposed into τ/H. Middle panel: same as in the left panel but for θ = 75.3^0 and 87.5^0. Notice the change in the sign of the net hysteretic response as $H \rightarrow H_{c2}$. Right panel: $\Delta\tau/H$ as a function of the field for θ=88.5^0 and for several temperatures. Black arrow indicates the minimum at H_{dia}, purple arrow the irreversibility field, and clear blue arrow the crossover from diamagnetic to paramagnetic-like hysteresis.

Conclusions

The lower-field diamagnetic response which is dominated by the pinning of vortices, crosses over to a state with a much smaller but "paramagnetic-like" hysteretic response which *disappears* at *Hc*2. Since diamagnetism results from screening super-currents, we conclude that this anomalous hysteretic response must result from super-currents circulating in the opposite sense which generate an effective moment as expected for a chiral superconductor.

Acknowledgements

L. B. is supported by DOE-BES through award DE-SC0002613.

References

[1] Kasahara, Y., *et al.*, Phys. Rev. Lett. **99**, 116402 (2007).
[2] Li, G., *et al.*, (under review).