Competing electronic ground states in $CeRh_2As_2$

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$CeRh_2As_2$ is one of a small number of materials exhibiting two distinct superconducting phases. This, plus a lack of local inversion symmetry and an upper critical field well above the Pauli limit led to proposals that $CeRh_2As_2$ hosts new topological quantum states and Majorana zero modes, suggesting its use in quantum computation. To uncover what gives $CeRh_2As_2$ such desirable properties, its resistivity (ρ_{xx}), Hall effect (ρ_{xy}) and magnetization were measured in pulsed fields of up to 73 T at temperatures down to 0.5 K. The low resistance of $CeRh_2As_2$ single crystals makes pulsed-field resistivity measurements challenging. Therefore, devices optimized for pulsed fields (Figure insets) were made using focused-ion-beam (FIB) methods, a cutting-edge technique combination. The devices allowed the current to be driven in different directions relative to the field and crystal axes.

The experiments (using the NHMFL 3D-printed goniometer to rotate devices to precise angles in the field), revealed the strongly anisotropic properties of $CeRh_2As_2$. Hence, detailed phase diagrams were derived for field *H* along the [100], [110] and [001] crystal axes. For *H* || [001], a kink in ρ_{xy} [Fig. (a)] signaled a large change in hole density due to a valence transition; as temperature grows, this moves to higher fields [Fig. (b)]. As with other Ce compounds, the valence transition is caused by *f*-electrons moving from the Fermi sea to Ce multiplets. For *H* || to [100] and [110], features in resistivity [Fig.(c)] showed three distinct phases (I, II, III), due to field-induced density-waves [Fig. (c,d)]; here, the *f*-electrons stay itinerant and the transitions represent changes in Fermi-surface nesting. The upper limit of the density-wave phases merges with the T_0 transition, a known precursor to superconductivity.

The fact that phase transitions of very different natures are induced just by changing the direction of the field shows that electrons in $CeRh_2As_2$ experience several competing interactions of a similar strength. In such a situation, the electrons exist in a delicate energy balance; small changes in a control parameter such as magnetic field, temperature or pressure can alter their quantum-mechanical state dramatically. It is from such a fertile ground that the unusual superconducting phases blossom.

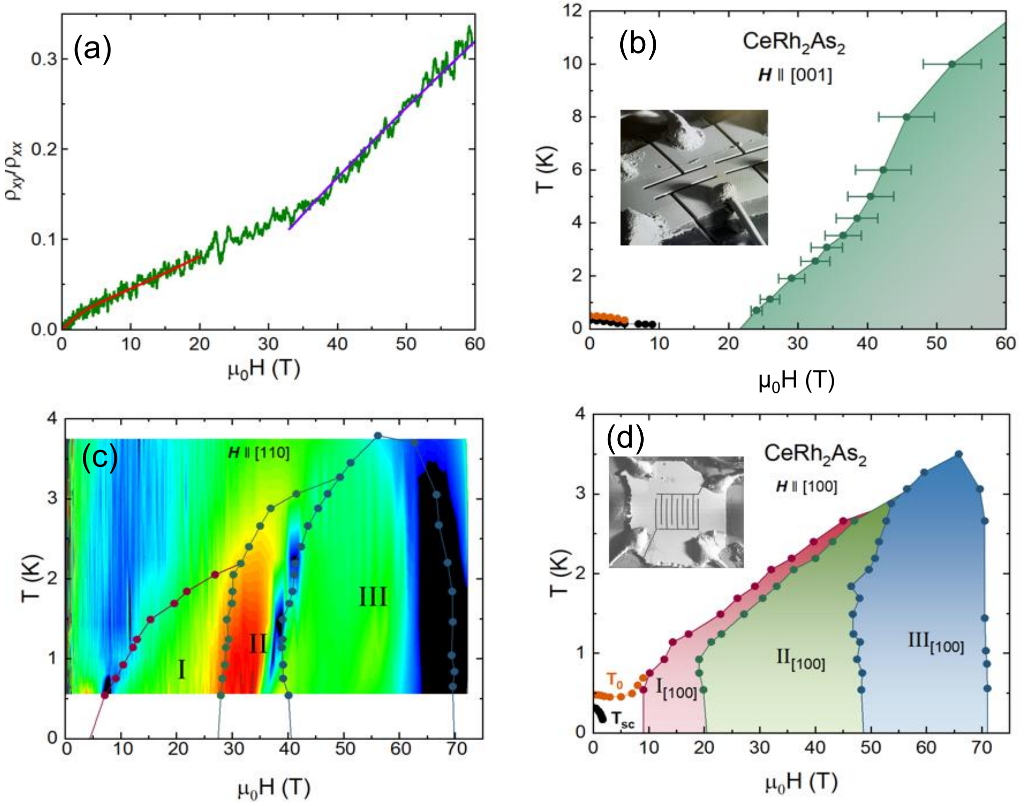

Figure: (a) ρ_{xy}/ρ_{xx} shows the kink due to the valence transition; data (green) are fitted by a model (red, purple) revealing the change in hole density. (b) Phase diagram for *H* || [001]; the superconducting phase is seen at low field. (c) Contour plots of $d\rho_{xx}/dH$ used to track boundaries (*H* || [110]) between density-wave phases. (d) Phase diagram of density-wave states, T_0 transition and superconductivity (H || [100]). Some of the FIB devices are shown in insets.

Facilities and instrumentation used: 65 T short-pulse and 73 T Duplex Magnet at Pulsed Field Facility

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