Field-induced quantum critical point and nodal superconductivity in the heavy-fermion superconductor Ce_2PdIn_8

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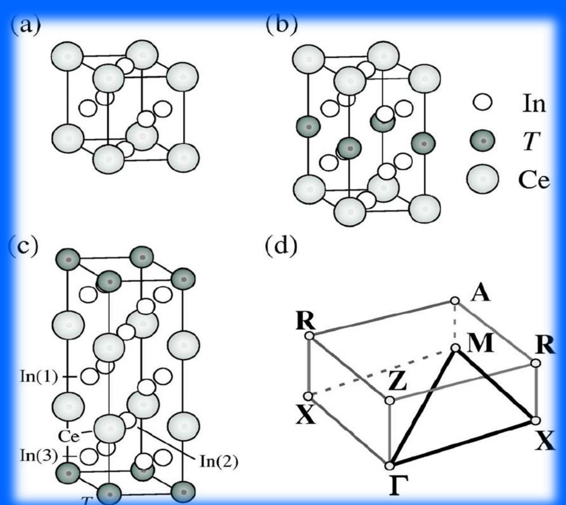
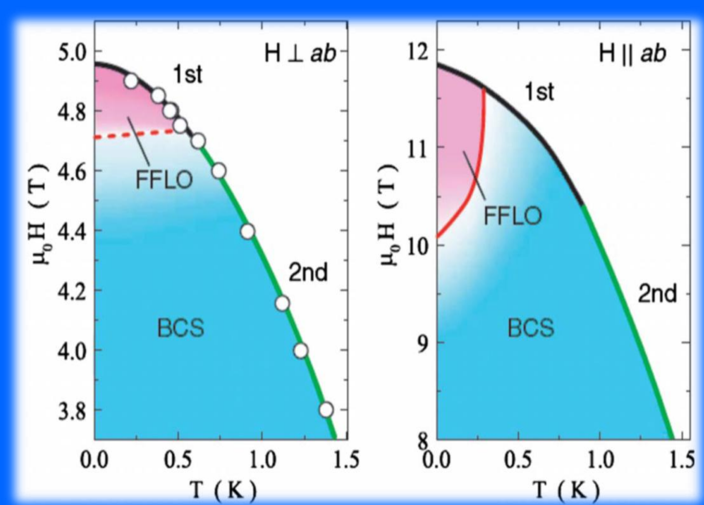
Introduction

The interplay between magnetism and superconductivity has been a central issue on unconventional superconductors. The Ce-based series Ce_nTIn_{3n+2} (T = Co, Rh, Ir) heavy-fermion superconductors have quasi-2D crystal structure and an enhanced Maki parameter α [1, 2]. The best candidate for an FFLO state known to date has been identified in $CeCoIn_5$ with T_c = 2.3 K at ambient pressure [3]. The possible FFLO state at the low-temperature-high-field (LTHF) corner of the H-T phase diagram has stimulated extensive studies.

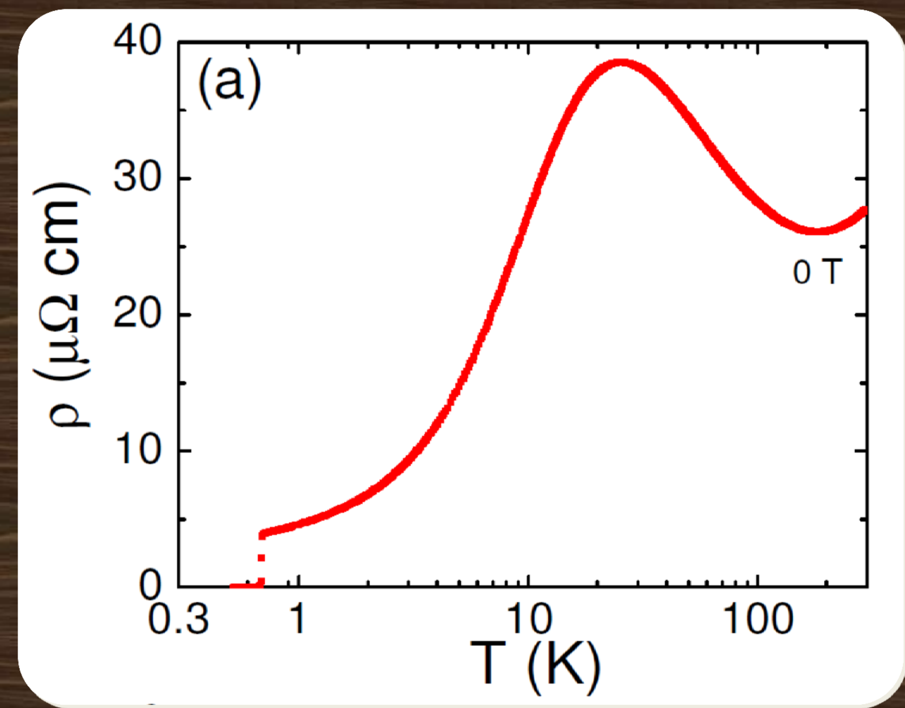
Recently, it was found that Ce_2PdIn_8 is also a heavy-fermion superconductor with T_c = 0.68 K. Ce_2PdIn_8 may also fulfill the requirements for the formation of FFLO state. Our low temperature transport results suggest that Ce_2PdIn_8 may also have exotic superconducting state as in $CeCoIn_5$ [3].



Crystal structure of Ce_nTIn_{3n+2}



Phase diagram of $CeCoIn_5$



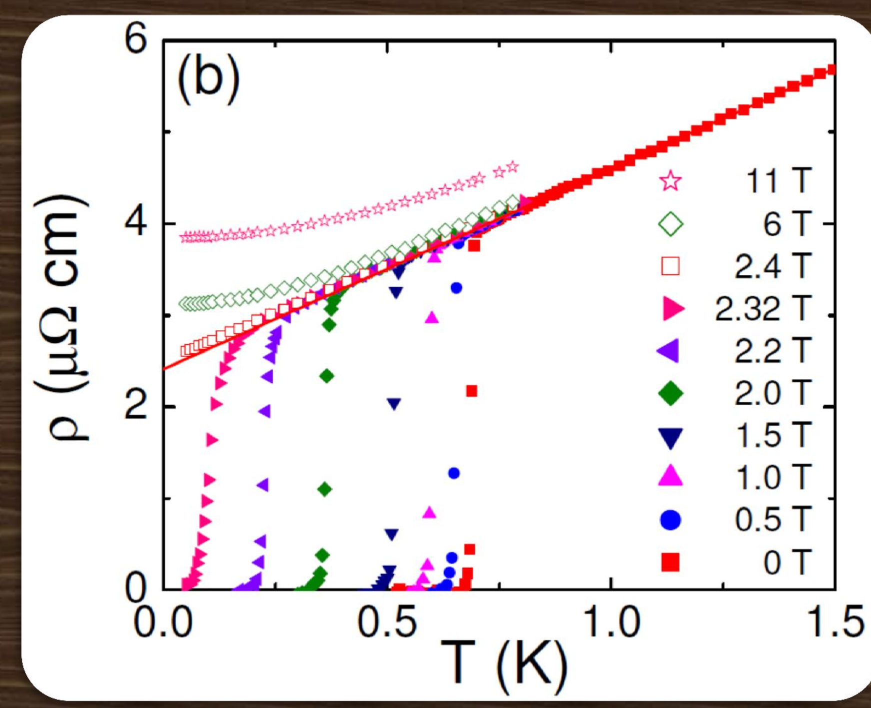
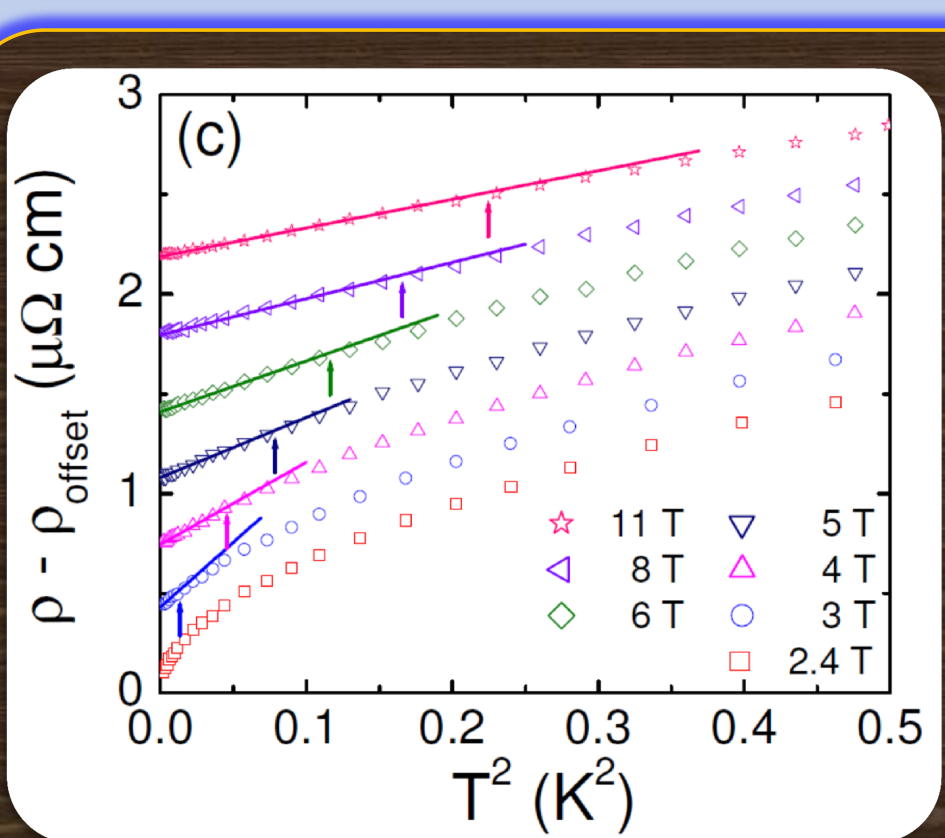
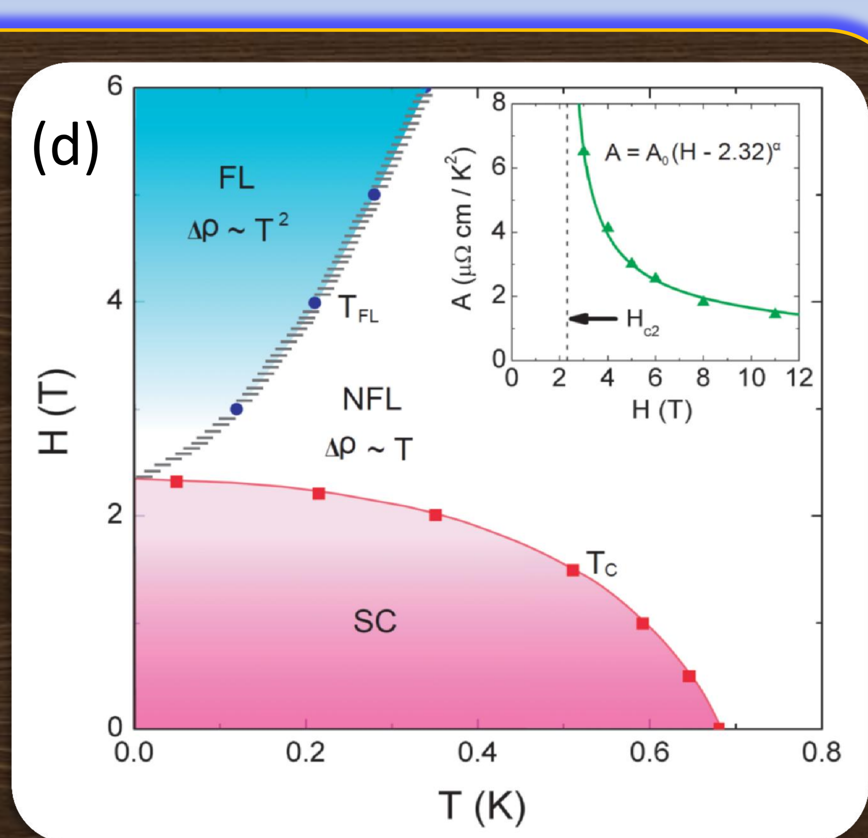


Fig. (a) shows the in-plane resistivity of Ce_2PdIn_8 single crystal in zero field. The curve is very smooth below 20 K, showing no impurity phases in the sample, especially the antiferromagnetic $CeIn_3$ with $T_N \sim 10$ K.

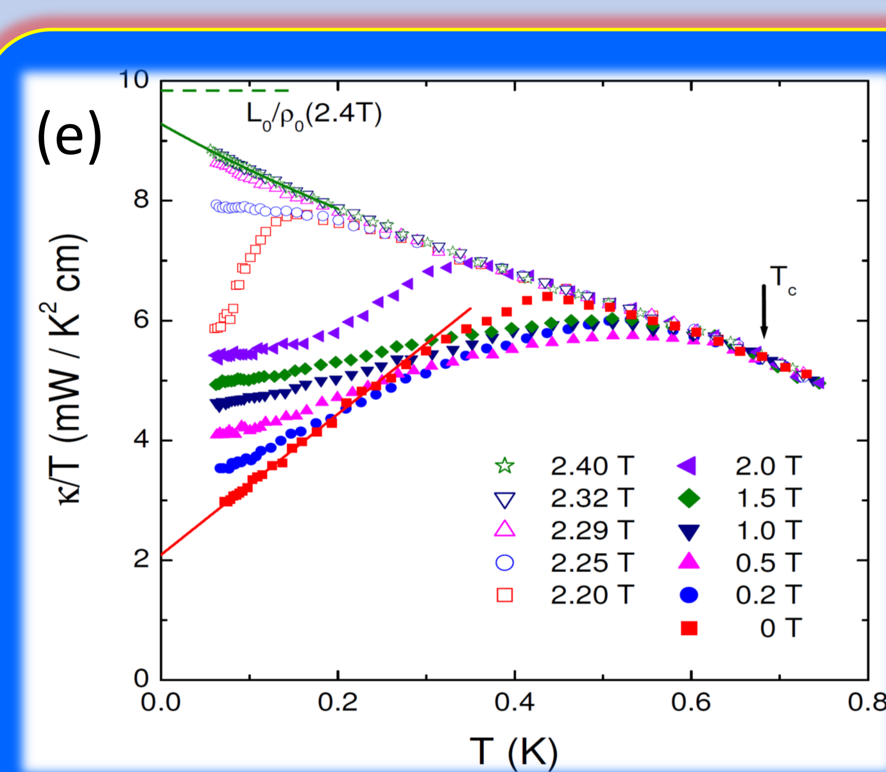
In Fig. (b), the low-temperature $\rho(T)$ in magnetic fields H∥c up to 11 T are plotted. From the zero-field data, T_c = 0.68 K is obtained, which is defined at the 10% of the normal-state value. The 10%-90% transition width is only 20 mK. It is found that ρ(T) obeys T-linear dependence nicely above T_c = 0.68 K, up to about 2 K. A linear fit of the data between 0.7 and 1.5 K gives a residual resistivity ρ_0 = 2.41 μΩ cm.

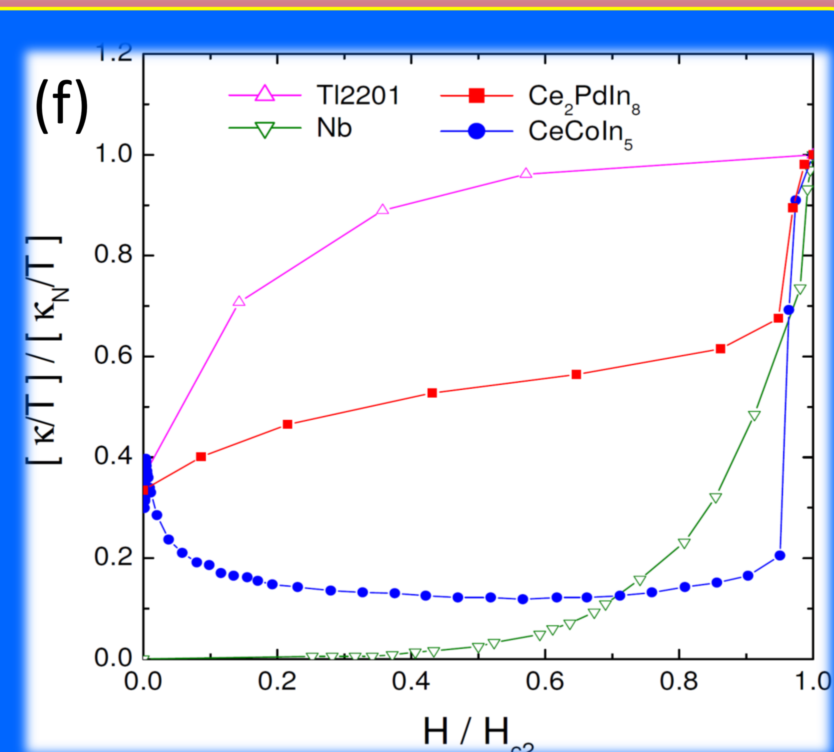




With increasing field, T_c gradually decreases, to 50 mK at H = 2.32 T. This field is determined as the bulk H_{c2} for H∥c. In slightly higher field H = 2.4 T, the resistive transition is completely suppressed, and the T-linear behavior of normal-state ρ(T) persists all the way down to 50 mK. In H > 2.4 T, The curves show clear deviation from the T-linear dependence. The data of H = 2.4, 3, 4, 5, 6, 8, and 11 T are plotted as ρ vs T^2 in Fig. (c). It is clearly seen that a Fermi liquid behavior of resistivity, $\rho \sim AT^2$, develops with increasing field. The inset of Fig. (d) plots the field dependence of the coefficient A, which tends to diverge towards H_{c2} = 2.32 T. The fitting of $A = A_0(H - 2.32)^\alpha$ gives α = - 0.57 ± 0.02.

Based on these resistivity results, we have constructed an H–T phase diagram for Ce_2PdIn_8 in the main panel of Fig. (d). Such a phase diagram is very similar to that of $CeCoIn_5$ [4], showing that there is also a field-induced QCP at H_{c2}.





In zero field, k/T of Ce_2PdIn_8 behaves similarly to that of $CeCoIn_5$ [5], increasing below T_c, showing a broad peak at ∼ 0.45 K, then decreasing towards T = 0. Below 250 mK, $k/T \propto T$ and extrapolates to k_0/T = 2.09 ± 0.02 mW K^{-2} cm^{-1}, more than 20% of the normal-state value. The significant k_0/T of Ce_2PdIn_8 is a strong evidence for nodes in the superconducting gap. The H = 2.4 T curve is fitted to $k/T = 1/(a + bT)$. The extrapolation gives k_0/T (2.4 T) = $1/a \approx 9.28$ mW K^{-2} cm^{-1}. This value is about 94% of the WF law expectation. The rough satisfaction of WF law in the normal state shows that our thermal conductivity data are reliable.

We plot k/T at 60 mK, normalized to its normal-state value, vs H/H_{c2} in Fig. (f). At low field (H/H_{c2} < 0.5), $k(H)/T$ of Ce_2PdIn_8 shows downward curvature as in Tl-2201 [6], providing further support for the nodes. A sharp jump of $k(H)/T$ is found near H_{c2}, which hints that the superconducting to normal state transition at very low temperature is first-order-like.

Conclusions

- Resistivity measurements of the Ce_2PdIn_8 show a field-induced quantum critical point occurrs at the upper critical field H_{c2}.
- Large residual linear term κ_0/T at zero field and the rapid increase of $\kappa(H)/T$ at low field give evidences for nodal superconductivity in Ce_2PdIn_8. The jump of $\kappa(H)/T$ near H_{c2} suggests a first-order-like phase transition at low temperature.
- Ce_2PdIn_8 meets the strict requirements for the formation of FFLO state and is another promising compound to investigate the exotic Q phase and FFLO state.

Reference

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See also preprint paper at arXiv:1008.0679