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ABSTRACT CODE

Superconductivity in $PuCoGa_5$

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The solid state of plutonium is among the most interesting unsolved problems of physics. Central to this problem is the ambiguity of Pu's electronic configuration; its 5f-electrons appear to be neither completely localized (magnetic and non-bonding) nor fully itinerant (bonding). The balance between these extremes is perturbed easily by changes in temperature, pressure, magnetic field and chemical surrounding, a hallmark of strong, non-linear coupling that also is found in certain cerium-based materials. These cerium materials are a simpler limit of Pu; the single 4f electron in cerium can assume only two configurations, while multiple configurations of the 5f-electrons are possible in Pu. As we have found [1], one of these 5f configurations produces superconductivity in single crystals of $PuCoGa_5$, which have a T_c exceeding 18.5 K, an upper critical field approaching 74 T and modestly large specific heat Sommerfeld coefficient γ=77 mJ/mol K^2. Some of these properties are shown in figure 1. The normal

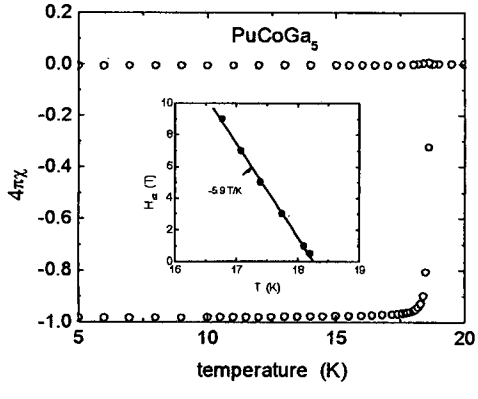

Fig. 1. Zero-field and field-cooled magnetic susceptibility of $PuCoGa_5$ measured in a field of 10 Oe. The inset shows the resistively measured upper critical field near T_c.

state out of which superconductivity develops has a susceptibility of the form $\chi = \chi_0+C/(T-\theta)$, where $\chi_0=5.1\times10^{-4}$ emu/mole, θ=-2K and effective moment $\mu_{eff}=0.68\mu_B$. A free-electron interpretation of the Pauli-like χ_0 would imply $\gamma\approx35$ mJ/mol K^2, slightly less than half the value deduced from specific heat measurements and suggesting that electronic correlations cannot be ignored.

This new compound can be viewed as being built from layers of δ-like Pu separated by a layer of '$CoGa_2$'. $PuCoGa_5$ crystallizes in a layered structure identical to that of $CeCoIn_5$, which is an unconventional, heavy-fermion superconductor but with nearly an order of magnitude lower T_c than its Pu-analog. Assuming that superconductivity in $PuCoGa_5$, as in $CeCoIn_5$, is mediated by antiferromagnetic spin fluctuations, the difference in possible f-electron configurations in Pu provides a higher spin-fluctuation temperature and potential explanation for the much higher transition temperature in $PuCoGa_5$. This possible interpretation extends to isostructural $PuRhGa_5$, also recently discovered [2] to be superconducting below 8.6 K; whereas, $CeRhIn_5$ is an antiferromagnet at atmospheric pressure.

As might be expected from its layered crystal structure, the electronic structure of $PuCoGa_5$ [3] and related compounds has a Fermi surface dominated by a nearly cylindrical sheet, leading to speculation that anisotropy may be important for superconductivity. Interestingly, within the series $CeM_{1-x}M'_xIn_5$, where M=Rh, Co and Ir, T_c appears to be a linear function of c/a, with c and a being the tetragonal lattice constants. Figure 2 shows that, within

experimental uncertainty, both the Ce and Pu compounds have the same huge slope $dT_c/d(c/a) \approx 80$ K, suggesting similar underlying physics.

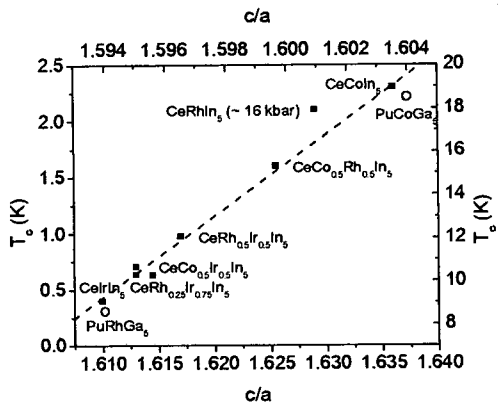

Fig. 1. T_c versus c/a for $CeM_{1-x}M'_xIn_5$, left and bottom axes, and for $PuCoGa_5$ and $PuRhGa_5$, top and right axes.

These observations, in light of isostructural $UCoGa_5$, which is not superconducting and has a small γ, place previously unavailable constraints on our understanding of Pu's 5f-electron configuration and the role of electronic correlations.

References

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[3] I. Opahle and P. M. Oppeneer, unpublished; T. Maehira et al., cond-mat/0212033; J. M. Wills, unpublished.