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A Novel Superconductor in Actinide Platinum Metal Borides

P. Rogl [1], O. Sologub [2], E. Bauer [3], H. Kaldarar [3], E. Roaynian [3], A.P. Gonçalves [2]

[1] *Institute of Physical Chemistry, University of Vienna, Währingerstrasse 42, 1090 Wien, Austria*
[2] *Dept. Química ITN / CFMC-UL, E. N. 10, P-2686-953 Sacavém, Portugal,*
[3] *Institute of Solid State Physics, Vienna University of Technology, A-1040 Wien, Austria*

Introduction: The discovery of $CePt_3Si$ ($CePt_3B$ type) as the first heavy fermion superconductor without a center of symmetry [1] has triggered widespread research activities to search for a novel superconducting state in related ternary or quaternary alloy systems [2]. Therefore, our studies were extended to actinoid metal-platinum metal-boride systems in search for novel materials with similar property characteristics and/or a possibly high Seebeck effect due to strong electron correlations. The aims of the research are: (i) detailed investigation of phase relations in the systems Th–Pd–B, Th–Pt–B, U–Pd–B, U–Pt–B, (ii) an evaluation of the crystal structures of ternary compounds and (iii) the characterization of physical properties of novel materials. The present paper summarizes results on the $ThPt_3B$ and UPt_3B compounds.

Experimental: Alloys $AnPt_3B$, *An* = Th, U (1.5 gram each) were prepared by argon arc-melting on a water-cooled copper hearth in Ti-gettered argon from elemental ingots (>99.9 mass%). All alloys were sealed in quartz tubes and annealed at $T = 900$°C for 100 h before quenching in cold water. X-ray powder diffraction data from as-cast and annealed alloys were collected on a Guinier–Huber image plate system with $CuK_{\alpha 1}$ ($8 < 2\Theta < 100°$). Refinement of the crystal structures was performed with the program Fullprof [3]. Measurements of the various physical properties were carried out with a series of standard techniques [4].

Phase relations: Phase equilibria in the {Th,U}–{Pd,Pt}–B systems were explored in the region <34 at.% *An* at 900°C, revealing a series of ternary compounds of which compounds with the composition close or at $ThPt_3B$ and UPt_3B where those with the lowest boron content. Homogeneous regions, if any, are certainly small, as unit cell parameters were not found to change significantly in ternary alloys. Neither isotypic UPd_3B nor isotypic $ThPd_3B$ (for details on the structure types see below) were found in our investigations and different structures (which are part of a forthcoming paper) were encountered at these compositions.

Crystal structure of $ThPt_3B$: Single crystals were isolated from the mechanically crushed alloy and showed a cubic primitive unit cell corresponding to $a = 0.4383(2)$ nm. X-ray intensities indicated isotypism with the filled $AuCu_3$ type structure i.e. a perovskite boride with Th atoms at the corners and Pt atoms at the face-centered positions of the cubic unit cell. For the boron atoms the sites in the center of the unit cell are the most likely ones, similarly to isotypic rare earth platinum metal borides $REPt_3B_{1-x}$.

Crystal structure of UPt_3B: Single crystals isolated from the mechanically crushed alloy indicated a tetragonal primitive unit cell with $a = 0.38906(3)$, $c = 0.52241(5)$ nm. The X-ray intensity spectrum indicated isotypism with the $CePt_3B$-type structure. This structure type lacks a center of symmetry and is also adopted by the heavy fermion superconductor $CePt_3Si$ [1]. From the refinement data the correspondence of U and Ce-atoms, and Si and B-atoms is straightforward: U in *1b* (1/2, 1/2, $z = 0.1621(6)$), Pt1 in *2c* (1/2, 0, $z = 0.6134(8)$), Pt2 in *1a* (0, 0, 0 (fixed)) and B in *1a* (0, 0, z=0.3521(10)). The low residual value, $R_F = 0.036$ for 110 reflections in a Rietveld refinement, confirms the structure type.

Superconducting $ThPt_3B$: Measurements of the temperature dependent electrical resistivity carried out at low temperatures reveal a superconducting transition around 0.75 K, if the resistivity drop taken at 50% is considered. The application of magnetic field suppresses T_C with an initial slope of about –0.83 T/K, extrapolating to an upper critical field at $T = 0$ well below 1 T. The almost linear dependency of $\mu_0 Hc_2'$(T) refers to some deviation from standard WHH-type behaviour [5] of the upper critical field. The temperature dependent resistivity in the normal state region does not comply with a simple metallic dependence; rather, $\rho(T)$ shows

a negative temperature coefficient, reminiscent of $TmPt_{\sim 3}Si$ [6]. Attempts were made to model $\rho(T)$ of both compounds in terms of weak localization. Magnetoresistance of this compound is below 1%.

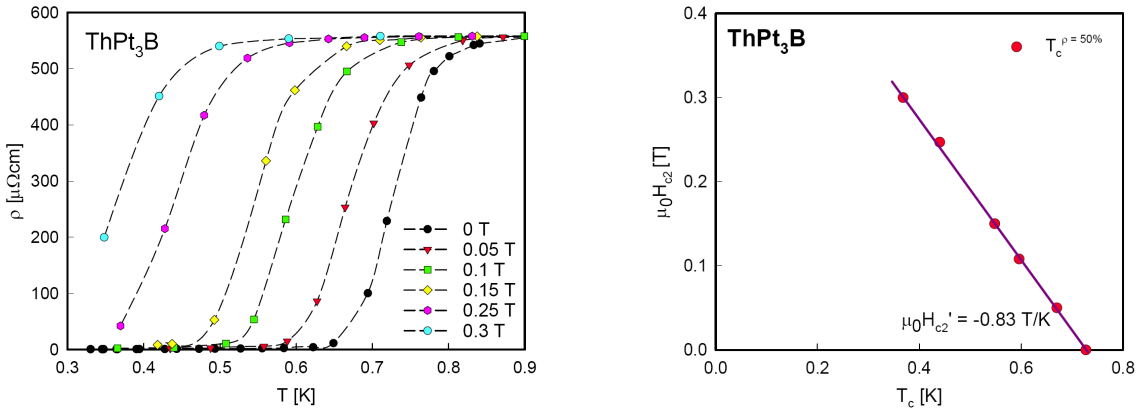

Fig. 1: (left panel) Temperature dependent electrical resistivity ρ of $ThPt_3B$ measured at various values of externally applied magnetic fields. (right panel): Temperature dependent upper critical field of $ThPt_3B$. The initial slope of $\mu_0 Hc_2$ is about -0.83 T/K (solid line).

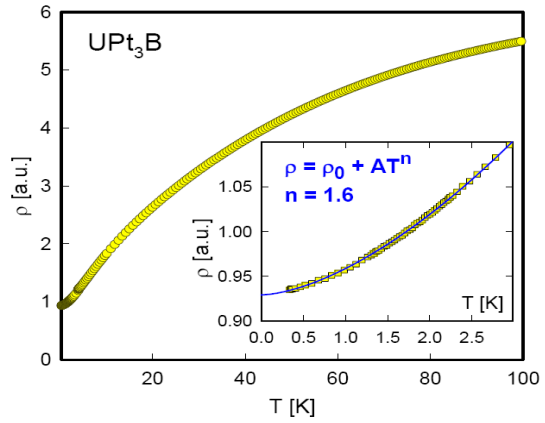

Fig. 2: Temperature dependent electrical resistivity ρ of UPt_3B. The inset shows low temperature details and the solid line is a least squares fit with n = 1.6.

Nonmagnetic UPt_3B: We have studied $\rho(T)$ of UPt_3B down to 340 mK. From resistivity measurements neither superconducting nor magnetic phase transition was observed. In contrast to $ThPt_3B$, metallic resistivity behavior was found in the entire temperature range. However, $\rho(T)$ does not follow simple metallic behavior; rather, at lowest temperatures a non-Fermi liquid characteristics, $\rho = \rho_0 + AT^n$ with $n = 1.6$ is observed.

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