NON-FERMI-LIQUID FEATURES OF NOVEL Yb_2Pd_2In*

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(Received July 10, 2002)

Yb in ternary Yb_2Pd_2In exhibits a valency $\nu \approx 2.9$ and consequently, no clear evidence of long range magnetic order down to 40 mK. Low temperature resistivity and specific heat are characterised by significant deviations from a Fermi-liquid (FL) scenario. While the application of magnetic fields recovers a FL state, pressure drives the system closer to a magnetic instability at $T = 0$.

PACS numbers: 75.30.Mb, 74.25.Bt, 75.30.Cr

Heavy fermion compounds close to a magnetic instability at $T_{\rm mag} = 0$ can be driven across a quantum critical point (QCP) by varying non-thermal parameters like chemical substitution, pressure or magnetic fields. Next to such a quantum critical regime a number of extraordinary properties are observable, see *e.g.* Refs. [1,2].

Several features make Yb compounds attractive to study low temperature anomalies; among them is the tuning of properties by alloying or pressure, which responds in most cases in a mirror-like manner when compared to Ce compounds. While for Yb compounds the parameters $JN(E_{\rm F})$ and

* Presented at the International Conference on Strongly Correlated Electron Systems, (SCES 02), Cracow, Poland, July 10–13, 2002.

T_K decrease upon increasing pressure, the opposite happens for Ce compounds. For that reason, pressure drives Yb systems towards the magnetic regime and possibly, the QCP is crossed from the non-magnetic side [3, 4]. In the present paper we aim to evaluate low temperature properties of crystallographically ordered ternary Yb_2Pd_2In. For the synthesis and crystal structure see Ref. [5].

In order to examine the possibility of magnetic ordering in Yb_2Pd_2In, Mößbauer spectra on the isotope ^{170}Yb were recorded down to 40 mK. Results of the 40 mK run are shown in Fig. 1(a). Spectra taken at 4.2 K and 40 mK are identical, and correspond to a quadrupolar hyperfine interaction alone, *i.e.* no hyperfine magnetic field is present. This shows that no magnetic ordering of the Yb^{3+} moments is present at this temperature, with moments larger than 0.05 μ_B. A least squares fit to the data (solid line, Fig. 1(a)), taking into account a non-axial quadrupolar hyperfine hamiltonian, reveals for the quadrupolar coupling parameter $\alpha_Q = 1.85$ mm/s, and for the asymmetry parameter $\eta = 0.4$, values typical for a paramagnetic Yb^{3+} ion at a site with non-axial symmetry.

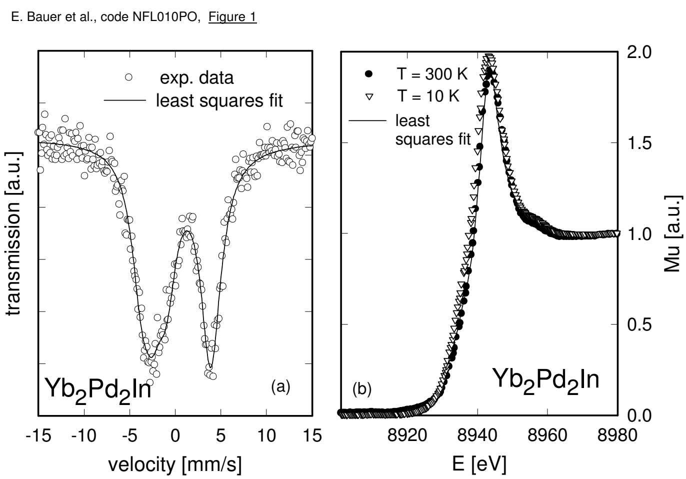

Fig. 1. (a) ^{170}Yb Mößbauer spectrum of Yb_2Pd_2In taken at 40 mK. The solid line is a least squares fit (see text). (b) L_{III} absorption spectra of Yb_2Pd_2In at $T = 300$ and 10 K. The solid line is a least squares fit.

The absence of magnetic order in Yb_2Pd_2In can be also concluded from X-ray absorption edge data. Results of L_{III} measurements taken at $T = 10$ and 300 K, together with a standard analysis, are displayed in Fig. 1(b). The valency of the Yb ion thus derived is $\nu = 2.89$, showing only insignificant temperature dependence. There is experimental evidence that already a slight drop of the valency from 3 causes a vanishing of magnetic order in Yb systems (see *e.g.*, $Yb(Cu,Al)_5$ [4]). Thus, Mößbauer and L_{III} data consistently prove a non-magnetic ground state in Yb_2Pd_2In. Moreover, the effective magnetic moment $\mu_{\rm eff} = 3.88\ \mu_B/$Yb, deduced from a Curie-Weiss like susceptibility for $T > 50$ K, is well below that of Yb^{3+}, which also makes magnetic order rather unlikely.

The overall shape of $\rho(T)$ (Fig. 2(a),(b)) is in line with a typical Kondo lattice: At high temperatures, the logarithmic contribution to $\rho(T)$ indicates incoherent Kondo scattering. The maximum at $T_\rho^{\rm max} \sim T_K$ roughly measures the Kondo temperature [6] and the decrease of $\rho(T)$ below $T_\rho^{\rm max}$ indicates coherent scattering. The pressure response of $\rho(T)$, Fig. 2(a), is characterised by three distinct features: *(i)* $T_\rho^{\rm max}$ lowers significantly from about 60 K ($p = 1$ bar) to below 30 K ($p = 16$ kbar) at an initial rate of $\partial T_\rho^{\rm max}/\partial T \approx -2.4$ K/kbar. *(ii)* The low temperature slope of $\rho(T)$ increases. *(iii)* The analysis of these data yields a huge Grüneisen parameter $\Gamma_e = -42$, reflecting a strong volume dependence of various physical quantities.

E. Bauer et al., code NFL010PO, Figure 2

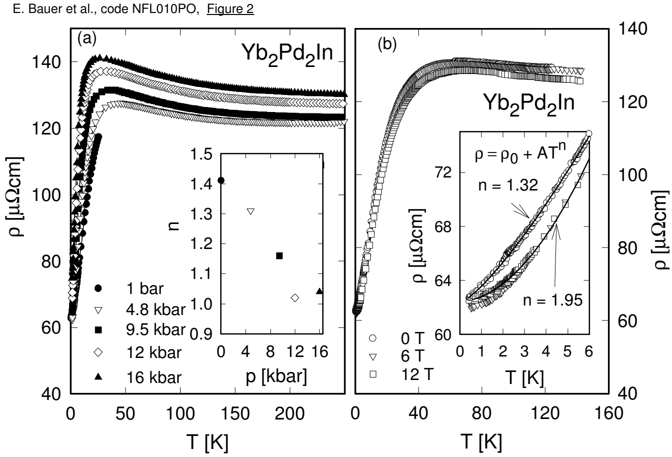

Fig. 2. (a) Electrical resistivity $\rho(T)$ of Yb_2Pd_2In for various values of pressure. The inset shows the the pressure dependent variation of the exponent n. (b) Electrical resistivity $\rho(T)$ of Yb_2Pd_2In for various values of applied fields. The inset shows low temperature details and the solid lines are least squares fits.

The low temperature behaviour of $\rho(T)$ is accounted for in terms of $\rho = \rho_0 + AT^n$ where ρ_0 is the residual resistivity; an exponent $n = 2$ would reflect a Fermi liquid behaviour of the system. Least squares fits to the low temperature data, however, indicate a substantially lower value of $n \approx 1.4$ at ambient pressure and as p increases, a decrease of n is derived with $n \approx 1$ for $p = 16$ kbar being indicative for non-Fermi-liquid behaviour. The evolution of $n(p)$ most likely indicates a shift towards the QCP of the system, and beyond the present pressure range long range magnetic order is expected.

The field dependence of $\rho(T)$, Fig. 2(b), is characterised by *(i)* an increase of $T_\rho^{\max}$ with growing fields and *(ii)* an increase of n approaching $n \approx 2$ for 12 T. The latter reflects the quenching of critical magnetic fluctuations and hence a Fermi-liquid behaviour is supposed to be recovered.

The temperature dependent specific heat of Yb_2Pd_2In is shown in Fig. 3 together with that of isomorphous non-magnetic La_2Pd_2In. Magnetic entropy is deduced from the difference of both samples and the continuous increase evidences that entropy release is spread over a broad temperature range due to Kondo interaction. Yb_2Pd_2In exhibits at $T \approx 2.2$ K a small anomaly in C_p/T due to traces of magnetically ordered Yb_2O_3. Below 2 K, C_p/T increases logarithmically, but levels off around 0.5 K. With increasing magnetic fields (not shown here), this feature is even shifted to higher temperatures. In view of the Mößbauer results, such a structure cannot be attributed to magnetic ordering, but may reflect a particular energy dependence of a non-Fermi-liquid ground state. Moreover, the shape of $C_p(T)$ around 500 mK does not resemble a typical spin glass.

In summary, Yb_2Pd_2In does not show long range magnetic order above 40 mK. Pressure and field dependent resistivity, as well as specific heat measurements rule out a simple Fermi-liquid ground state.

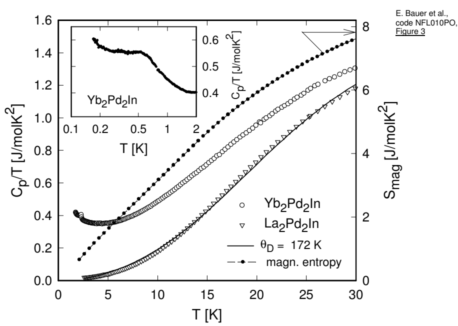

Fig. 3. Temperature dependent specific heat C_p plotted as C_p/T *vs* T of Yb_2Pd_2In and La_2Pd_2In. The solid line is a fit to the Debye model; magnetic entropy refers to the right axis. The inset shows low temperature features in Yb_2Pd_2In.

Work supported by the Austrian FWF P12899 and ESF, project FERLIN.

REFERENCES

[1] H. von Löhneysen, *J. Magn. Magn. Mat.* **200**, 532 (1999).
[2] P. Coleman, *et al.*, *J. Phys.: Condens. Matter* **13**, R723 (2001).
[3] O. Trovarelli, *et al.*, *Phys. Rev. Lett.* **85**, 626 (2000).
[4] E. Bauer, *et al.*, *Phys. Rev.* **B60**, 1238 (1999).
[5] M. Giovannini, *et al.*, *Intermetallics* **9**, 481 (2001).
[6] D. Cox, *et al.*, *Z. Phys.* **B71**, 321 (1988).