Point contact properties of intermetallic compound YbCu_{(5-x)Al_x} (x = 1.3 – 1.75)

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YbCu$_{3.5}$Al$_{1.5}$ is a well-known example of a non-Fermi liquid (NFL) system crystallizing in the hexagonal CaCu$_5$ structure. Major characteristic NFL features of this compound (our sample) include:

- Negative logarithmic contribution to the specific heat
- Substantial deviations of the electrical resistivity from a $T^2$ dependence, $T^n$ where $n < 2$

These were proven in E. Bauer et al., Phys. Rev. B60 (1999) 1238.

Proximity to a quantum critical point was demonstrated considering the self consistent renormalization model – preference to spin fluctuations by Ch. Seuring et al., J. Low Temp. Physics 123 (2001) 25.

Magnetic field suppresses the NFL behaviour - 12 T probably sufficient to recover a FL state.


Only a few reports of PCS of NFL systems exist.

**Motivation**

**Figure 5.** Specific heat $C_p$ of various YbCu$_{1-x}$Al$_x$ alloys plotted as $C_p/T$ on a logarithmic temperature scale.

$x = 1.3$ – Kondo lattice

$T_K = 31$ K

$x = 1.4$ – NFL behaviour

$x_{cr} = 1.5$ - NFL behaviour

$x = 1.6$ – magnetic ordering

$T_N = 0.25$ K

$x = 1.75$ – magnetic ordering

$T_N = 1$ K

FIG. 12. Concentration dependence of characteristic temperatures of YbCu$_{5-x}$Al$_x$; $T_{p,\text{low}}^{\text{max}}$ is the low-temperature maximum of the electrical resistivity, $T_0$ is the scaling temperature according to Eq. (1). The antiferromagnetic ordering temperature $T_N$ for $x = 1.6$ and $x = 1.7$ as well as $T_K$ are taken from Ref. 5. The concentration range between the hatched areas is the approximate extension of the NFL.
Point contact spectroscopy

- PC means a metallic constriction with size $d$ smaller than mean scattering length $l$ of conduction electrons
- Applying of voltage to the contact – conduction electrons gain an energy $\sim eV$
- PC spectroscopy - scattering of conduction electrons with other quasiparticles in metals
- First derivative $dV/dI(V)$ of $I-V$ characteristic – dynamic resistance
- Second derivative $d^2V/dI^2(V)$ of $I-V$ characteristic – directly proportional to the electron quasiparticle interaction (EQI)

Wexler formula:

$$R_{PC}(T) \sim \frac{16\rho l}{3\pi d^2} + \frac{\rho(T)}{d}$$

1. ballistic - $l_{el}, l_{in} \gg d$
2. diffusive - $l_{el} << d \ll (l_{el} l_{in})^{1/2}$
3. thermal - $l_{el}, l_{in} \ll d$

$\rho l \approx 10^{-11}\Omega\text{cm}^2$
$\rho = 100 \mu\Omega\text{cm (4 K)}$
$l \approx 1-10\text{ nm}$
Results

dV/dI curves versus V for YbCu$_{3.5}$Al$_{1.5}$ – YbCu$_{3.5}$Al$_{1.5}$ (solid line) and YbCu$_{3.5}$Al$_{1.5}$ – Pt (dots) at 1.5 K.

Comparison of dV/dI for heterocontact YbCu$_{3.5}$Al$_{1.5}$ – Pt at 0.1 and 6 K.
\[ \begin{align*} 
\frac{dV}{dI}(V)^s &= \frac{[dV/dI(V > 0) + dV/dI(V < 0)]}{2} \\
\frac{dV}{dI}(V)^{as} &= \frac{[dV/dI(V > 0) - dV/dI(V < 0)]}{2} 
\end{align*} \]

**Results**

dV/dI curves versus V for YbCu$_{3.5}$Al$_{1.5}$ – Pt (solid line), symmetric part of dV/dI (dash line) and asymmetric part of dV/dI (dash dot line) at 1.5 K.

Comparison of dV/dI for homocontact YbCu$_{3.5}$Al$_{1.5}$ – YbCu$_{3.5}$Al$_{1.5}$ (solid line) vs. symmetric part of heterocontact YbCu$_{3.5}$Al$_{1.5}$ – Pt (dash line) at 1.5 K.
Results

$R = \frac{1}{d} \int_0^1 \rho (T_{\text{max}} \sqrt{1 - x^2}) \, dx$

$T_{\text{max}}^2 - T_0^2 = V^2/4L$

$R = \frac{\rho}{d}$

(i) increased residual resistivity of the metal inside the constriction (Naidyuk et al 1993); (ii) a spoiled, poorly conducting interface layer (Nowack et al 1992, Gloos et al 1998); (iii) a low transparent barrier at the boundary (Naidyuk et al 1991b); and (iv) strong reflection of the electrons by mismatch of the effective masses or Fermi momenta of the contacting metals (Gloos et al 1995a).
Results

Characteristic magnetic field behaviour of dV/dI for heterocontact YbCu$_{3.5}$Al$_{1.5}$ – Pt at 1.5 K.

R$_{PC}$(B) for heterocontact YbCu$_{3.5}$Al$_{1.5}$ – Pt at 1.5 K.
Conclusions

• needle anvil arrangement of PC
• high $\rho$ in orders $100 \mu\Omega \text{cm}$, short mean free path
• maximu close to zero; homocontact – origin YbCu$_{5-x}$Al$_x$
• contradiction to thermal regime (calculated)
• in magnetic field – $dV/dI(V, B)$ similar to $\rho(T, B)$
• asymmetry due to NFL features?
• more suitable MCBJ – higher $R_{PC}$
• YbRh$_2$Si$_2$ $\rho$ in orders $1 \mu\Omega \text{cm}$, single crystal

G.Pristáš, M.Reiffers, E.Bauer: Point-contact properties of non-Fermi liquid compounds YbCu$_{5-x}$Al$_x$ ($x = 1.3, 1.4$ and $1.6$) in the vicinity of QCP, Physica B 378-380 (2006) 100-101.

Oral presentation CSMAG’07: Point Contact Spectroscopy of Non-Fermi Liquid Compound YbCu$_{5-x}$Al$_x$ ($x = 1.3$ - 1.75) In High Magnetic Fields

-review paper - homocontacts, high magnetic fields…