Eletron transport studies of UCu_5Al and $U_{1-x}Th_xCu_5Al$

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UCu_5Al with a tetragonal structure (space group *I4/mmm*) undergoes antiferromagnetic transition at $T_N = 18$ K [1-2]. Specific heat $C_p(T)$ and electrical resistivity $\rho(T)$ measurements have revealed an enhancement of the C_p/T ratio (180 mJ/K^{2}mol at 0.35 K) and the Kondo-like behaviour of $\rho(T)$, classifying this compound to be a medium heavy-fermion system. Recently, specific heat as well as electron transport measurements on single crystals of this compound have evidenced the existence of a competition between the Kondo effect and Ruderman-Kittel-Kasuya-Yosida inter-actions. This feature, together with the frustration of magnetic interactions is believed to be important for the development of the heavy-fermion (HF) state in UCu_5Al [3]. With the aim to provide new information on the nature of the complicated HF state, we have measured electrical resistivity under high pressure up to 30 GPa on UCu_5Al single crystals and in high magnetic fields up to 14 T on the $U_{1-x}Th_xCu_5Al$ solid solutions.

The pressure experiments were carried out on three crystals with the configuration j // a using a low-pressure cell (up to P = 6 GPa, sample 1), a medium-pressure (up to 15 GPa, sample 2) and a high-pressure cell (up to 30 GPa, sample 3). The resistivity at the ambient pressure of sample 2 (see inset of Fig. 1) is characterised by a –lnT behaviour at high temperature, a broad maximum at T_{max} ~50 K and a rapid increase in the resistivity below T_{min}. The latter feature is presumably due to the opening of an energy gap due to the onset of the antiferromagnetism at T_N. With increasing pressure, T_{max} shifts to higher temperatures. An interpretation for this behaviour can be given provided that T_{max} scales with the Kondo temperature T_K. Since the density of states $N(E_F)$ is weakly altered by P, the observed increase in $T_{max} \propto [T_K \propto \exp(-1/JN(E_F))]$ points to an enhancement of the exchange coupling parameter J.

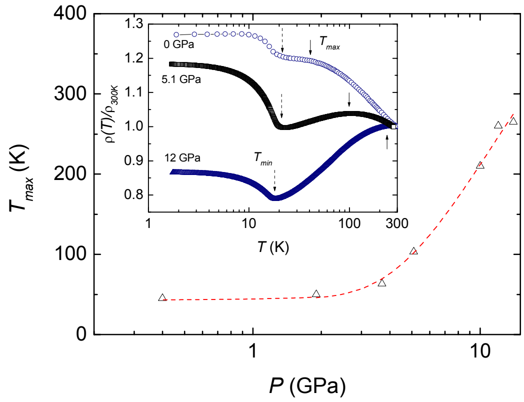

Fig. 1 Pressure dependence of T_{max}. The inset shows $\rho(T)/r_{300K}$ as a function of T at selected pressures.

The influence of the pressure on magnetic exchange interactions may be examined by inspecting the pressure dependence $T_N(P)$, which is approximately equal to T_{min}. As can be seen from Fig. 2, T_N decreases initially linearly upon pressure up to 5 GPa, and then goes through a maximum at about 8 GPa. Since there is no sudden change in the shape of ρ(T) for P < 15 GPa (see Fig. 1), the anomalies in the $T_N(P)$ dependence cannot be caused by any crystallographic change. However, the analysis of the $T_N(P)$ dependence has revealed some points Noteworthy. Firstly, the complex change of $T_N(P)$ may suggest the existence of some different magnetic couplings, having different responses to P. Secondly, within the Doniach lattice model, the observed behaviour of $T_N(P)$ is in contrast to the expected monotonic decrease caused by an enhancement of magnetic exchange coupling. In other words, the correlation between T_N, T_K and T_{RKKY} for UCu_5Al is questionable below 12 GPa.

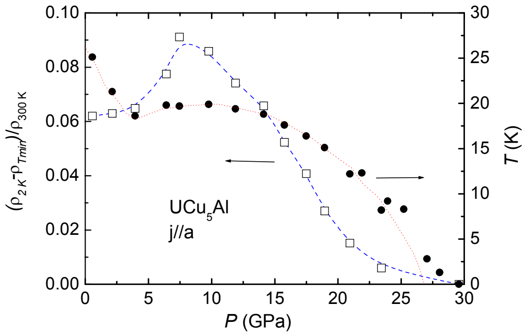

Fig. 2 Pressure dependence of the Néel temperature and the ratio $(\rho_{2K} - \rho_{Tmin})/\rho_{300K}$.

Of particular interest is an unusual pressure dependence of the ratio $(\rho_{2K}-\rho_{Tmin})/\rho_{300K}$, shown in Fig. 2 (left hand scale). Assuming that the pressure has a little effect on the resistivity originating from the atomic disorder scattering on defects and/or impurities, we are able to ascribe the pressure dependence of $(\rho_{2K}-\rho_{Tmin})/\rho_{300K}$ to some magnetic effects. The presence of a maximum in the $(\rho_{2K}-\rho_{Tmin})/\rho_{300K}$ vs P curve at $P \sim 8$ GPa provides a strong evidence on the existence of two competing phenomena; the increasing role of the Kondo effect and the closing of the energy gap. These two phenomena should affect the magnitude of the $(\rho_{2K}-\rho_{Tmin})/\rho_{300K}$ ratio upon pressure. Note that the maximum in the $(\rho_{2K}-\rho_{Tmin})/\rho_{300K}$ vs P curve coincides with the maximum in $T_N(P)$. At higher pressures, T_N decreases with increasing P and a transition from the magnetic to a non-magnetic state takes place at a pressure of about $P_c = 27$ GPa. At P = 30 GPa, a $\rho \propto T^2$ dependence is observed up to $T = 15$ K.

In Fig. 3 we show the electrical resistivity at zero field and 10 T as a function of temperature for $U_{0.7}Th_{0.3}Cu_5Al$. The zero-field resistivity in the high temperature range coincides with that previously reported [2]. However, below ~ 4 K the resistivity shows a clear increase, indicating the onset of the antiferromagnetic order as in UCu_5Al. The application of a field of 10 T leads to a depression of ρ, resulting in a negative magnetoresistance (MR) (see Fig. 3b). In magnetic fields up to 14 T, Δρ/ρ(B) of all investigated solid solutions (x = 0.05, 0,2, 0.3) (not shown here) is negative in the temperature range 2-50 K. A common feature is a curvature of Δρ/ρ vs B, signifying the strong influence of Kondo interactions.

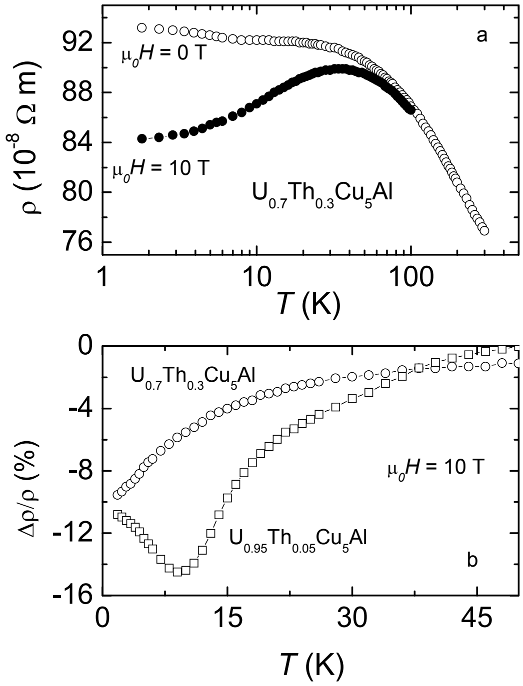

Fig. 3 (a) Temperature dependence of the resistivity of $U_{0.7}Th_{0.3}Cu_5Al$, measured at zero and 10 T. (b) Magnetoresistance of $U_{0.95}Th_{0.05}Cu_5Al$ and $U_{0.7}Th_{0.3}Cu_5Al$ as a function of temperature.

A remarkable feature of MR observed for UCu_5Al as well as for x = 0.05 is the occurrence of a minimum in Δρ/ρ vs T near T_N.

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References:

[1] R. Troć et al.,*J .Magn. Magn. Mater* 183 (1998) 132.

[2] R. Troć et al., *Acta Physica Polonica A* 97 (2000) 25.

[3] V. H. Tran, et al. *Phys. Rev B* 66 (2002) 54421.