High Pressure Study of Yb-heavy Fermion Compounds Near Magnetic Instability

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One of the main goals of the work is to explore the ground state properties of Yb-based heavy-fermion (HF) systems at/near a magnetic quantum critical point (QCP). This is a fundamental issue for a deeper understanding of the nature of electron correlations and the associated anomalous quantum critical phenomena in strongly correlated electron systems. Here the basic idea is to tune the ground state properties of proper Yb-based HF systems across a magnetic QCP by applying external pressure.

In order to investigate the change of the lattice parameters and volume near a QCP, we have measured the pressure dependence of the lattice parameters and volume of two Yb-based HF compounds YbIr$_2$Si$_2$ (I-type ThCr$_2$Si$_2$ structure, space group $I4/mmm$) and YbAgGe (hexagonal ZrNiAl-type structure, space group $P-6 2m$). These compounds are located close to a QCP. The former, YbIr$_2$Si$_2$, has been found to be a new HF compound situated very close to the magnetic QCP [1]. However, YbIr$_2$Si$_2$ is situated on the nonmagnetic side and thereby can be tuned by pressure across the QCP to go to magnetically ordered state.

![Diagram of pressure dependence of cell volume of YbIr$_2$Si$_2$.](image)

Figure 1: Pressure dependence of the cell volume of YbIr$_2$Si$_2$. Inset shows the relative change of a and c-axis under pressure.

We performed energy dispersive x-ray powder diffraction (EDXRD) at beamline F3, HASYLAB, using diamond anvil cell (DAC) setup with liquid nitrogen as pressure transmitting medium. The beam collimated to a size of about $100 \times 100$ μm$^2$ hit the sample in a cylindrical sample chamber of about 200 μm in diameter. The detector collecting the diffraction photons was situated at an angle of 3.5° with respect to the direction of the incoming beam. Typical data acquisition time for one spectrum was about 30 minutes. In the Fig. 1 plot have been shown up to 25 GPa. It is evident from the inset of Fig.1 that there is no structural transition. Birch-Murnaghan equation of state [2] has
been used to obtain the parameters: \( V_0 \) and \( B_0 \) are the value of the unit cell volume and bulk modulus at \( p = 0 \) GPa, and \( B'_0 = (dB/dp)_{p=0} \). These results are now essential to understand the planned pressure dependence of the resistivity and \(^{170}\)Yb Mössbauer spectroscopy.

On the other hand, the compound, YbAgGe exhibits AFM ordering at 0.65 K and 1 K [3, 4]. We have recently performed high-pressure electrical transport measurements on YbAgGe up to 20 GPa. The analysis of the data reveals a sharp rise of \( T_N \) with increasing pressure up to 7 GPa. However, further increase in pressure gives rise to a sharp reduction in \( T_N \), approaching zero around 15 GPa, suggesting a delocalization of the Yb 4f moment. This finding is quite contrary to the general expectation of a stable pressure-induced localized 4f moment. In order to prove whether such anomalous behaviour is not due to the structural transition, we performed EDXRD under high pressure. Fig. 2 shows the results up to 20 GPa and it is obvious that there is no structural transition.

In conclusion, we have performed EDXRD of two Yb-based HF compounds, YbIr\(_2\)Si\(_2\) and YbAgGe under pressure. The former one was studied up to 25 GPa while the latter up to 20 GPa. Neither of the two compounds shows any evidence of structural phase transition. Bulk modulus of YbIr\(_2\)Si\(_2\) is found to be two times higher than that of YbAgGe. To understand the electron correlation effect, it is necessary to investigate more Yb-compounds in different regions of Doniach’s magnetic phase diagram [5], particularly in the proximity to a magnetic QCP.

References