Quantum Criticality and its Anisotropy in the Quadrupole Ordered System PrV$_2$Al$_{20}$

Shimura, Y.; Nakatsuji, S.; Tsujimoto, M. (Institute for Solid State Physics, University of Tokyo); Zeng, B.; Zhang, Q. and Balicas, L. (NHMFL, FSU)

Introduction

The cubic quadrupolar Kondo lattice PrV$_2$Al$_{20}$ with the $\Gamma_3$ non-magnetic doublet ground state having orbital (quadrupole) degrees of freedom exhibits an antiferro-quadrupole ordering at 0.6 K. In the quadrupole ordered state, a superconducting transition has recently been found with a heavy quasi-particle mass at 0.05 K. Under an applied magnetic field, $H_c \sim 11$ T for $H // [111]$, we found a field-tuned quantum critical behavior [1]. Above the critical field, we also observed quantum oscillations which is associated with heavy electron mass [2]. This result indicates that the origin of the field-induced quantum criticality is due to the competition between an ordered state of the localized quadrupole moment below $H_c$ and the Kondo-like screened state for quadrupole moments coupling with the conduction electrons above $H_c$.

Experimental

Single crystal of PrV$_2$Al$_{20}$ were synthesized by Al self-flux method, using a home-made vertical tube furnace and temperatures up to ~ 1400 °C. We have measured the magnetoresistance $\rho(H, T)$ for magnetic fields, mainly, parallel to the [110] direction and down to 23 mK at the SCM1 facility.

Results and Discussion

Figure 1 shows the field dependence of the magnetoresistance $\rho(H)$ in PrV$_2$Al$_{20}$ for $H // [110]$ and [111]. $\rho(H)$ for $H // [110]$ exhibits distinct hysteresis for fields between 13 T and 16 T, suggesting a first-order transition in addition to the shoulder like anomaly at ~ 8 T. These behaviors differ from that of $\rho(H)$ with $H // [111]$. Figure 2 shows the magnetic phase diagram for $H // [110]$ constructed from $\rho(H, T)$. This phase diagram indicates that the other high-field ordered state remains in regions bounded by fields between 8 T and 13 T [3]. This is evidence that the quadrupolar order parameter changes when exceeding magnetic field of 8 T. A similar high-field phase for $H // [110]$ is also discussed in the cubic PrPb$_3$, indicating antiferro-quadrupole ordering. The emergence of the high-field phase is universal phenomena for the cubic Pr-based compounds with a $\Gamma_3$ doublet ground state.

Conclusions

We measured the magnetoresistance of PrV$_2$Al$_{20}$ for $H // [110]$. A first-order transition and kink were observed at 13 T- 16 T and 8 T, respectively. These give us key information in clarifying the quadrupolar order parameter.

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References