ANOMALOUS IRREVERSIBILITY IN $C_p(T)$ AND MCE NEAR A QUANTUM CRITICAL POINT IN U(Ru,Rh)$_2$Si$_2$

A. V. Silhanek (NHMFL, LANL); V. Fanelli (Phys. and Astron., UCI); M. Jaime; N. Harrison (NHMFL, LANL); H. Amitsuka (Hokkaido Univ., Japan); and J. A. Mydosh (MPICPS, Dresden, Germany).

We have measured the specific heat and magneto-caloric effect in the moderate heavy fermion system U(Ru$_{1-x}$Rh$_x$)$_2$Si$_2$. The chemical substitution of Rh for Ru induces changes in the conduction electron density giving rise to profound effects even for very diluted Rh-doping. At the particular concentration $x=4\%$ this compound exhibits a much simpler $H$-$T$ phase diagram than the stoichiometric parent URu$_2$Si$_2$, with a single field-induced magnetic phase, known as phase II, surrounding a quantum critical point (see Figure 1).

We show that the phase emerging as a result of a QCP exhibits a clear irreversible behavior at low temperatures, characteristic of a first order transition. Indeed, fast (quasi-adiabatic) sweeps of the magnetic field reveal a strong hysteresis between magnetizing and demagnetizing processes when crossing the border phase. One of these MCE measurements is shown in Figure 2(a). In the sweep up curve, at $H \sim 27$ T, a clear increase of the temperature appears indicating that the system has penetrated into a phase with higher magnetic order. Within this regime $T(H)$ remains roughly constant until leaving the phase-II at $H \sim 37$ T, this time accompanied by a clear negative temperature spike.

Another systematically observed feature is that as temperature decreases the height of the spike becomes larger when incoming phase-II than exiting it. A similar effect has been observed$[1]$ in YbInCu$_4$ where a first order valence transition accompanied by an abrupt change of the lattice structure is observed. In both cases, the adiabatic increment of temperature $\delta T$ can be thought of as a resultant of a (standard) reversible $\delta T_{\text{rev}}$ component and an (anomalous) irreversible contribution $\delta T_{\text{irr}}$. In contrast to $\delta T_{\text{rev}}$, regardless the direction in which the phase boundary is crossed, the irreversible component is always positive as the system relieves heat following mechanisms analogous to internal friction processes. According to this picture, a not yet observed structural change in the crystal lattice may also occur in the phase-II boundary.

The region where the irreversibility in the magneto-caloric effect occurs coincides with an anomalous asymmetry between cooling and warming in the specific heat (see Figure 2(b)). Additionally, specific heat measurements present an unexpected time dependence that can be consistently explained within a metastability induced phases picture.

References