Magnetotransport Near A Quantum Critical Point

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Introduction

The physics of quantum critical phase transitions connects to some of the most difficult problems in condensed matter physics, including metal-insulator transitions, frustrated magnetism and high temperature superconductivity. Near a quantum critical point (QCP) a new kind of metal emerges, whose thermodynamic and transport properties do not fit into the unified phenomenology with which we understand conventional metals - the Landau Fermi liquid (FL) theory - characterized by a low temperature limiting T-linear specific heat and a T^2 resistivity [1]. Studying the evolution of the T dependence of these observables as a function of a control parameter leads to the identification both of the presence and the nature of the quantum phase transition in candidate systems. In this study we measure the transport properties of BaFe2(As1-xPx)2 at T < Tc by suppressing superconductivity with high magnetic fields. At sufficiently low temperatures, the resistivity of all compositions (x = 0:31) crosses over from a linear to a quadratic temperature dependence, consistent with a low temperature FL ground state. As compositions with optimal Tc are approached from the overdoped side, this cross-over becomes steeper, consistent with models of quantum criticality where the effective Fermi temperature TF goes to zero.

Experimental

We have measured transport to extremely high fields, up to 65T. These allow us to measure the transport power law at temperatures below Tc.

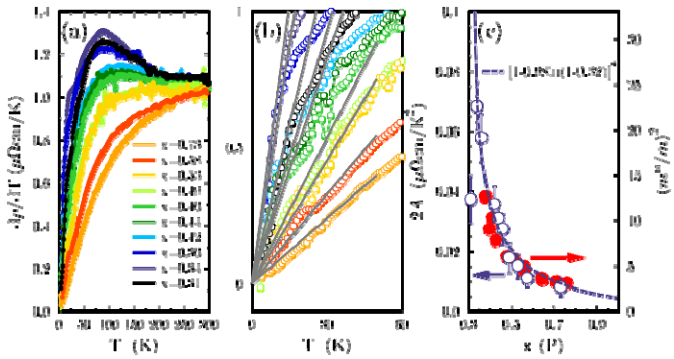

Figure 1: Derivative of the resistivity interpolated over the full temperature range. (a) The derivative of the resistivity for all samples in Figure 2, including data from zero field and high field experiments, interpolated to form differentiable curves. (b) An enlargement of the data shown in (a) with linear fits to the low T behavior (grey lines). (c) The dramatic increase in the value 2A (open circles) at compositions between x = 0:73 and 0:37, suggests the proximity of a QCP below the superconducting dome. The data is consistent with the KWR15 $A=m^{*2}$ = constant, as can be seen by comparing with previous determinations of the effective mass m*. The line is a fit to a phenomenological divergence of the effective mass near a QCP [2] $[C0 - C1\ln(x-xc)]^2$, with x_c = 0:32. Error bars have been determined using the standard deviation of the data from the least-squares fit.

Conclusions

In marked contrast to the situation found for hole-doped cuprates, where the T-linear resistivity remains robust over an extended range of doping[3], BaFe2(As1-xPx)2 is found to exhibit behavior associated with a more conventional picture of quantum criticality in which □(T) always crosses over from a T-linear to a T2 dependence below a temperature scale that diminishes on approach to the QCP. In accordance with this picture, the coefficient of the T2 resistivity is also found to diverge as the QCP is approached. Though there is at present no accepted theory explaining the origin of T-linear resistivity in quantum critical metals, a common point of view is that it is associated with Fermi-surface 'hot-spots' - regions of the Fermi surface with strongly enhanced scattering. Such regions are thought to dominate the transport of many strongly-correlated metals, particularly as disorder increases, accounting for the strong dependence of the scattering on T. The iron-based superconductors are likely to have hot spots on both electron and hole Fermi surfaces due to the proximity of the AFM order, and necessarily disordered due to doping. Our data can be broadly understood in this context - as an AFM QCP is approached from the overdoped side, the Fermi surface hot spots become increasingly 'hotter,' sharply changing the nature of the transport as a function of temperature. However, why it is that the resistivity is strictly T-linear and why this dependence is common to so many metals near a QCP remains an open question.

References

[1] Landau, L. Journal of Experimental and Theoretical Physics 6, 920 (1957).
[2] Abrahams, E. & Si, Q. Journal of Physics: Condensed Matter 23, 223201 (2011).
[3] Cooper, R. A. et al. Science 323, 603–607 (2009).