Hall effect indicates destruction of large Fermi surface at a heavy-fermion quantum critical point.

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Recommended and a Commentary by Zachary Fisk, University of California, Davis.

There is now a sizeable experimental data base addressing the heavy-fermion quantum critical point (QCP) and its associated finite temperature non-Fermi liquid properties in the cone in temperature/tuning parameter space fanning out above the singular T=0K critical point. Much of the data concerns the T-dependence of properties such as electrical resistivity and specific heat. Neither of these, for example, gives an unequivocal answer to what is happening electronically at the QCP. A central question here, perhaps the simplest, is how many electrons are counted within the Fermi surface and does this change across the QCP?

In the quite beautiful experiment discussed here, the Hall effect is measured as the T_N=70mK antiferromagnetic transition of the heavy-fermion tetragonal material $YbRh_2Si_2$ is tuned towards T=0K with magnetic field, this field either being parallel or perpendicular (H_{crit}= 0.06T parallel to the c-axis, 5T perpendicular) to the Hall generating field. Both configurations show an anomaly in the low field field-dependent Hall response which extrapolates to the same T=0K QCP when scaled by H_{crit}. A reasonable parametrization of the field dependent data show the Hall number n (from R_H=1/nec) varying between discreet limits on either side of the field tuned QCP, with the variation sharpening towards a step function as T --> 0K. The interpretation of this is that we are seeing a clean transition from localized to itinerant behavior of the Yb 4f-hole. The numbers actually work out to be that Δn=1 hole across the transition.

It seems a wonderful piece of good luck that this is visible in the low field Hall which in a multi-band material does not have a simple interpretation. But things seem to work out here. It is worth noting that the T-dependence of the Hall response has not been measured for the non-heavy-fermion counterpart $LuRh_2Si_2$: in the La-analogues of the 115-series of Ce heavy-fermion materials Hundley found marked T-dependence (cond-mat/0402076).

The 4f-hole appears to localize through the QCP into the antiferromagnetic state in spite of the fact that the order parameter for this antiferromagnetism is itself going to zero at the QCP. One localized 4f-hole, loosely speaking, fills a Brillouin zone, and delocalization doubles the possible occupancy of the zone. Thinking in terms of the Gibbs free energy, the result says that its derivative with respect to the chemical potential is discontinuous at the QCP, the signature of a first order phase transition. It is interesting to consider how analogous is the gas-liquid critical point and its accompanying critical opalescense.

A similar study has been carried out by Bud'ko et al. (cond-mat/0406435 v3) on the hexagonal intermetallic YbAgGe, whose 1K order can be driven to a QCP in applied fields of 4.5T and 8.0T, perpendicular and parallel to the c-axis respectively. The results resemble qualitatively what is found by Paschen et al. here, although the analysis is less detailed. It is interesting and perhaps strange that in neither case does one see any anomaly in the Hall response on crossing the antiferromagnetic phase boundary: the cross over appears separated from this boundary and is still visible in the H-T plane at temperatures of a few Kelvin when T_N is below 0.1K.

This excellent study does not put everything to bed. Checking things out in Ce heavy-fermions is clearly of great interest, life being complicated with these due to the quite general occurrence of superconductivity. With Uranium heavy-fermions, the situation might be somewhat different: here we see the quite general survival of large electronic specific heat γ's in the magnetically ordered states, unlike the usual situation in 4f heavy-fermions. The idea proposed by Fulde and Zwicknagel, that there may be co-existing localized and itinerant 5f-electrons in U-materials, if true may cause the physics to play out differently for these members of the heavy-fermion family.