The Hall effect in quantum critical $CeAuSb_2$

2011 J. Phys.: Conf. Ser. 273 012015

(http://iopscience.iop.org/1742-6596/273/1/012015)

International Conference on Strongly Correlated Electron Systems (SCES 2010) IOP Publishing
Journal of Physics: Conference Series **273** (2011) 012015 doi:10.1088/1742-6596/273/1/012015

The Hall effect in quantum critical $CeAuSb_2$

A. M. Strydom‡

Physics Department, University of Johannesburg, PO Box 524, Auckland Park 2006, South Africa

E-mail: amstrydom@uj.ac.za

A. Thamizhavel

Department of Condensed Matter Physics and Materials Science, Tata Institute of Fundamental Research, Mumbai 400005, India.

Abstract. $CeAuSb_2$ forms in a two-dimensional structure type with plates of $CeSb_2$ separated by layers of Au and Sb atoms respectively. Kondo effect and moderate heavy fermion characteristics are evident. Antiferromagnetic order occurs at low temperature with magnetic moments along the interplanar [001] direction. We have established $T_N = 5.6$ K from $B = 0.01$ T, $\mathbf{B} \parallel \mathbf{c}$ Squid magnetometric measurements. The same field orientation presents furthermore metamagnetic behaviour at $B_{meta1} = 2.6$ T and at $B_{meta2} \simeq B = 5.4$ T, as was also previously reported in the literature. It is known that continuous suppression of the magnetic order at T_N by applied field leads to a quantum critical point at a critical field $B_c = 5.4$ T. Here we present and discuss results of Hall effect measurements up to applied fields of 14 T on single-crystal $CeAuSb_2$, a property that offers the possibility to distinguish between types of quantum criticality. Analysis of the field-dependent Hall effect show a jump in the Hall resistivity close to B_c, the temperature dependence of which suggests that for $CeAuSb_2$ the jump evolves into a discontinuity at $T = 0$ K, $B = B_c$. Our results are interpreted in terms of local-moment quantum criticality in $CeAuSb_2$.

PACS numbers: 71.27.+a, 75.20.Mb, 73.50.Jt, 64.70.Tg

‡ A major part of the experimental work was done at the Max Planck Institute for Chemical Physics of Solids, Dresden

1. Introduction

A large volume of experimental and theoretical work has been devoted to gaining a deeper understanding of the physics at work in the quantum critical (QC) state [1]. The magnetic order parameter appears to have been especially amenable as a scale with which to measure the approach to a quantum phase transition which is, by definition, located at $T = 0$ K. The QC state is manifested in physical properties close to the phase transition at finite temperatures however, and since the work of Coleman *et al* [2] in which the modality of change in the Fermi surface at a QC point was connected with the quasiparticle behaviour across this point, the Hall effect has been of special interest. In contrast to for instance the low-temperature logarithmic or power-law temperature dependencies observed in electrical resistivity, specific heat or magnetic susceptibility and which are taken as fingerprints of quantum criticality, the enduring feature of Hall effect studies of heavy-fermion systems [3] is the possibility it offers to distinguish between the local-moment ordering picture involving the breakdown of heavy quasiparticles at a QC point, and the spin-density wave scenario in which heavy quasiparticles rather exist on *both* sides of the QC point. The scope of details found in the non-Fermi-liquid behaviour of systems close to a QC point has led to the notion of non-universality of the QC state, but the case of universality has been made for the quasiparticle linewidth close to the QC state [4]. It is therefore of interest to broaden the scope of experimental parameters with which to study the QC state.
In this work we focus on Hall effect measurements on $CeAuSb_2$. It adopts the tetragonal crystal structure of space group $P4/nmm$ [5]. The strong two-dimenionality of the structure is conducive to highly anisotropic electronic transport and magnetic properties [6]. A Kondo interaction on the Ce $4f-$electron moment is evident in the $\mathbf{j} \parallel \mathbf{c}$ electrical resistivity in the higher-temperature paramagnetic region. The ground state is magnetic: antiferromagnetic (AF) order sets in at $T_N = 5.6$ K and the $c-$axis, which is also the crystallographic stacking direction, is the easy axis of magnetization [6]. The AF ordering can be suppressed in a continuous manner to zero by applied magnetic fields [7] and electronic and magnetic properties convert into non-Fermi-liquid temperature dependencies in the process. It is of special interest that a metamagnetic transion is seen in the easy-axis magnetization of $CeAuSb_2$ well within the ordered region at 2 K, in a field of about 2.5 T [6, 7]. The AF transition at T_N, as well as this metamagnetic feature are both inconspicuous in the basal plane magnetization [6].

2. Experimental and Results

Procedures for growing single-crystal specimens of $CeAuSb_2$ have been described elsewhere [6]. A platelet was selected for Hall effect measurements in the ac-transport option of a PPMS station (Quantum Design, San Diego). Hall voltage measurements were collected as function of field at a number of temperatures, with field reversal in

order to eliminate non-orthogonal voltages.
Figure 1 illustrates field scans of the Hall resistivity $\rho_H(B)$ of $CeAuSb_2$ at a number of temperatures close to T_N. The magnetic field was applied along the easy axis of magnetization, $\mathbf{B} \parallel \mathbf{c}$, and excitation current was applied within the basal plane. The sample was demagnetized thermally in zero field between successive scans. Starting from a zero Hall signal at zero field, small ρ_H values are evident in small fields up to about 2.6 T. Our magnetization measurements (not shown) confirmed this as the field value of the lower one of two metamagnetic transitions known [6, 7] to occur in $CeAuSb_2$. The high-field regions for all isotherms are not only linear-in-B, but they also exhibit the same slope which means that here the Hall coefficient $R_H = \Delta\rho_H/\Delta B$ is field− and temperature *in*dependent. Taking profit from this and to isolate the anomaly in the transition region near B_c, we subtracted the high-field background line from each of the isotherms to yield a bare Hall resistivity, plotted for selected temperatures in Fig. 2 (left).

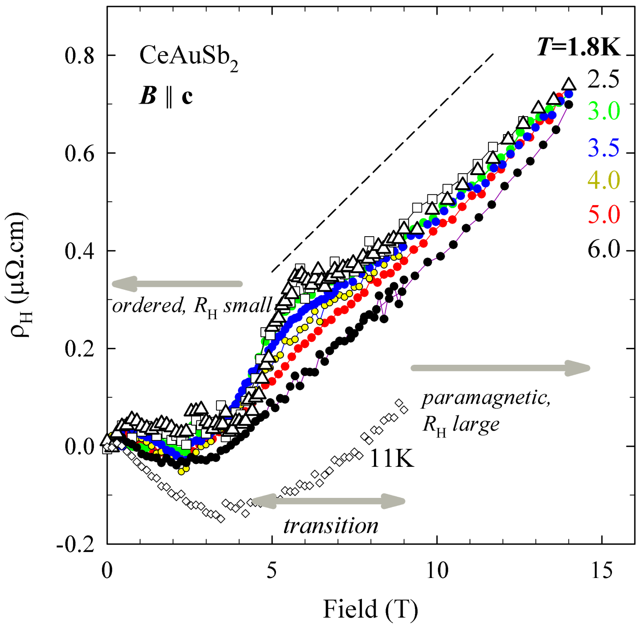
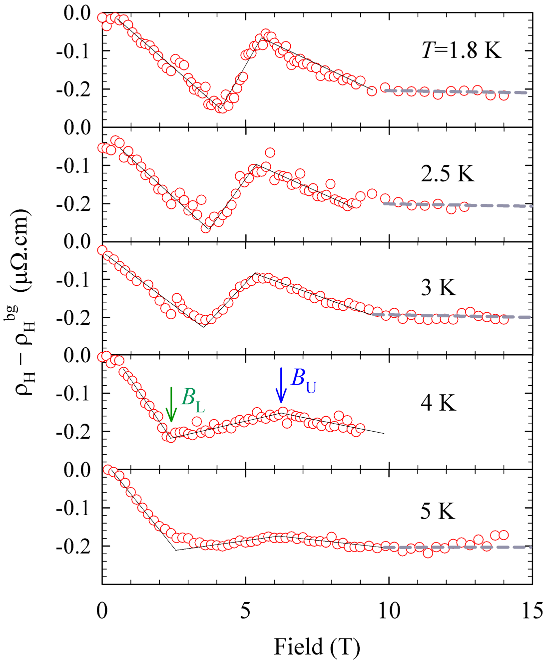


Figure 1. Field dependent Hall resistivity $\rho_H(B)$ of $CeAuSb_2$ at a number of temperatures spanning the T_N = 5.6 K AF order. The dashed line emphasizes the high-field $R_H = \Delta\rho_H/\Delta B = constant$ behaviour. This is used as a background and subtracted from the $\rho_H(B)$ curves - resulting difference curves are plotted in Fig. 2. A transition region separates small R_H values at the low-field magnetically ordered region from the high-field, large Hall coefficient, paramagnetic region. Note that equally large R_H values are found (although of negative sign) in the low-field 11 K paramagnetic isotherm.

In the conventional view of heavy fermions, a heavy Fermi liquid is formed by hybridization between the conduction- and f-electrons which is characteristic of the Kondo effect. The heavy Fermi liquid exists on both sides of a QC point, and the Fermi surface volume which accommodates both types of electrons, needs to be suitably large. The more unconventional local QC point [8] occurs when a metal undergoes a phase transition from the local f-electron magnetically ordered state into a paramagnetic phase with itinerant f-electrons. In this case the localization of f-electrons in the ordered phase removes them from the quasiparticle fluid. A reduced and smaller Fermi surface now accommodates just the conduction electrons. Our results can be reconciled with the latter view, i.e. of a *local quantum critical point* in $CeAuSb_2$. Comparing the Hall coefficient values $R_H = \Delta\rho_H/\Delta B$ obtainable from Fig. 2, the reduced Hall coefficient



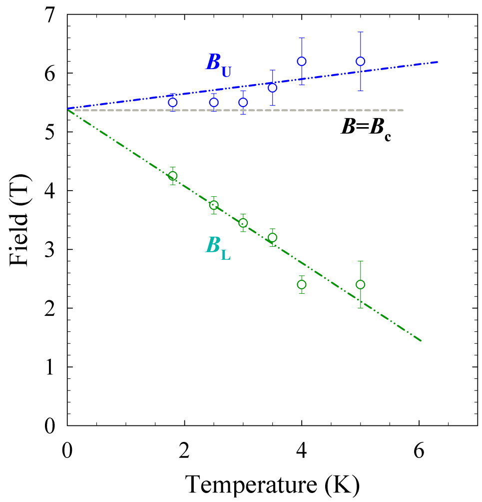


Figure 2. (left) Bare Hall resistivity $\rho_H - \rho_H^{bg}(B)$ of $CeAuSb_2$ obtained by subtracting a linear-in-B background (see Fig. 1). The high-field regions (upward of ~ 9 T) are flat, which is a consequence of a field *in*dependent Hall coefficient at high B. At lower B, two successive distinct turning points are observed; a minimum at B_L and a maximum at B_U. The turning points sharpen up considerably and close in on each other with lowering temperatures. (right) Temperature dependence of the minima B_L and maxima B_U found in the bare Hall resistivity curves. Lines are guides to the eye and interesect in the point ($T = 0, B = B_c = 5.4$ T), suggesting a discontinuity in the Hall coefficient at this point.

values from the low-field, $T < T_N$ isotherms are associated with the magnetically ordered state in which ordered local moments are not accommodated in the Fermi surface volume. The high-field region on the other hand, as well as the low-field, $T > T_N$ ranges exhibit large Hall coefficients which portray a large Fermi surface volume in which the composite $f - c$ quasiparticles need to be counted. AMS acknowledges the SA-NRF (2072956) and UJ-URC for financial assistance.

References

[1] see e.g. *Proc. Int. Conf. Quantum Criticality and Novel Phases 2009* ed Frank Steglich, Oliver Stockert, and Steffen Wirth *Phys. Stat. Sol. B* **247**.
[2] Coleman P, Pépin C, Si Q, and Ramazashvili R 2001 *J. Phys.: Condens. Matter* **13** R723
[3] Paschen S 2006 *Physica B* **378-380** 28
[4] Schlottmann P 2006 *Phys. Rev. B* **73** 085110
[5] Sologub O, Hiebl K, Rogl P, Noël H, and Bodak O 1994 *J. Alloys Comp* **210** 153
[6] Thamizhavel A *et al* 2003 *Phys. Rev. B* **68** 054427
[7] Balicas L *et al* 2005 *Phys. Rev. B* **72** 064422
[8] Si Q 2006 *Physica B* **378-380** 23