

Magnetoresistance and Hall effect of antiferromagnetic uranium compound URhIn₅

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Abstract. Magnetoresistance and Hall effect in URhIn₅ have been measured across the antiferromagnetic transition temperature $T_N = 98$ K. In the paramagnetic state, Hall coefficient is small and temperature independent. Below the T_N , Hall coefficient suddenly changes to a negative value, suggesting that small light electron Fermi surface dominate electrical conductivity. The observation is consistent with small Fermi surfaces detected by previous de Haas-van Alphen experiment.

1. Introduction

Actinides and rare-earth compounds with the tetragonal HoCoGa₅-type structure (115 compounds) have extensively been studied because of the emergence of intriguing physical properties such as heavy fermion superconductivity and various types of magnetic ordering.[1] Substituting elements within the same structure enables us to study carrier doping and/or chemical pressure effects without changing lattice symmetry. In isostructural actinide compounds, uranium analogues can be formed as UTGa₅ where T stands for transition metal elements of group 8, 9 and 10. In contrast to rare-earth analogues which are formed with indium, those with uranium and other actinides are usually stabilized with gallium, reflecting the smaller atomic size of uranium than light rare-earths. URhGa₅ is known as a non-magnetic semimetal where 5*f* electrons are itinerant to form conduction bands. Bulk physical properties and small Fermi surface pockets detected by the de Haas-van Alphen effect are consistent with semimetallic behavior.[2] It is interesting to note that the substitution of Rh by adjacent metals (Ru or Pd) alters the ground state: URuGa₅ is also non-magnetic, but expected to have large Fermi surfaces. UPdGa₅ is an antiferromagnet with large Fermi surfaces. The similar features are observed in the series of UTGa₅ with T = 3*d* (Fe, Co, Ni) and T = 5*d* (Os, Ir, Pt).[3] Together with the band structure calculations investigation, the substitution of the transition metal leads to a shift of the Fermi level in a relatively rigid band structure. [4]

Recently the first member of uranium 115 compounds having indium as a constituent elements, URhIn₅, has been synthesized in a single crystal form [5]. Unlike the isostructural and



nonmagnetic URhGa₅, URhIn₅ orders antiferromagnetically with a significantly high transition temperature $T_N = 98$ K. More recently, a higher transition temperature 117 K has been reported for U₂RhIn₈ having the similar local structure.[6] Reflecting the larger atomic size of In than Ga, URhIn₅ has the larger interatomic distances, leaving an effectively large space for uranium atoms. Naively thinking, a larger atomic size leads to a localized state of $5f$ electrons with a magnetic ground state. The drastic difference of magnetic ground state also leads to a difference conduction band structure. In this paper, we report magnetoresistance and Hall effect measurements of URhIn₅.

2. Experimental

Single crystals of URhIn₅ have been grown from indium flux as described in ref. [1]. The sample was shaped in a rectangular bar for the transport measurements. Magnetoresistance and Hall resistivity were measured using an AC four-probe method in a temperature range between 2 and 300 K. Magnetic field up to 9 T was applied along the tetragonal c -axis, while the electrical current was applied along the a -axis.

3. Results and Analysis

Figure 1 shows the temperature dependence of magnetoresistance and Hall coefficient R_H of URhIn₅. In the paramagnetic state above 98 K, resistivity at 9 T coincides with that in 0 T, namely magnetoresistance is negligibly small. R_H in the paramagnetic state also shows temperature-independent and small values. The value is much smaller than that expected for a single carrier per unit cell volume (1.0×10^{-9} m³/C). This is most likely due to multi-band effects. In general the conduction bands can involve many bands from different orbitals. The small values can arise from an accidental cancellation of the contributions from different bands. It should also be noted that the absence of the temperature dependence indicate that anomalous Hall effect often observed in magnetic actinide compounds is not significant in the paramagnetic state of URhIn₅.

In the antiferromagnetic state below $T_N = 98$ K, situations change drastically. With decreasing temperature, resistivity at 9 T gradually deviates from the 0 T values. Positive magnetoresistance is observed at low temperatures below about 50 K. R_H shows an abrupt change at T_N . R_H shows negative values in the antiferromagnetic state and depends strongly on temperature. R_H decreases continuously with decreasing temperature below T_N , showing a minimum at 40 K and increase again with decreasing temperature. Negative sign indicates that the electron-like carrier mainly dominates electrical conduction. The R_H value at 40 K exceeds the value expected for a conventional one-carrier value, suggesting the smaller carrier number in the ordered state. This interpretation is consistent with the gap formation on the Fermi surface as suggested from a hump in the resistivity just below T_N . On the other hand, strong temperature dependence can be attributed to different contributions from bands with different characters.

To understand the complicated behavior in R_H , we assume a simple two-band compensated metal with a relatively small carrier number. In fact, at least one small Fermi surface pocket occupying a few per cent of Brillouin zone is found in the de Haas-van Alphen experiments.[7] In the analysis we assumed the contribution from anomalous Hall effect is small also in the antiferromagnetic state. Within the two-band model, the carrier number $n = 0.055$ per paramagnetic unit cell for the electron and hole bands was obtained in the antiferromagnetic state. This value is of the same order as the carrier number deduced from the Fermi surface volume obtained in the previous dHvA study. This result demonstrates the existence of small number of carrier in the antiferromagnetic state and reinforces the idea that a portion of the Fermi surface is gapped at T_N as suggested from resistivity behavior. Moreover, the present

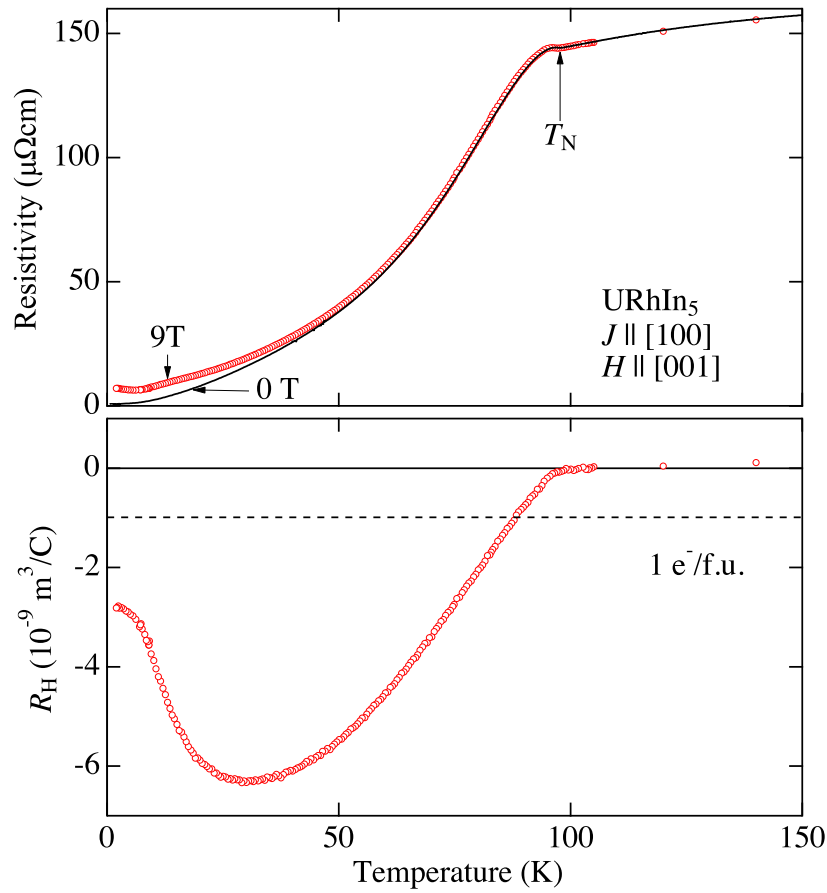


Figure 1. Upper panel: Temperature dependence of electrical resistivity in URhIn₅ measured at 0 T and 9 T. An arrow indicates the Néel temperature. Lower panel: Temperature dependence of Hall coefficient in URhIn₅ at 9 T. Dashed line in lower panel corresponds to the Hall coefficient expected for one conduction electron per unit cell volume.

result denies the possible existence of larger Fermi surfaces which dHvA could not detect due to heavier mass and hence weak signal amplitudes.

We omit to analyze the data at $T < 30$ K, because our simple assumption of the compensated two-band picture might not be valid. Magnetoresistance follows H^2 above 30 K and the present two-band analysis seems valid. However, a clear deviation from H^2 dependence is observed below 30 K. The detailed analyses of the field dependence are needed to understand the low-temperature behavior. The Hall resistivity also becomes field-dependent, most likely due to complicated multi-band effects beyond the simple two-band picture. It should be noted, however, that there are several experimental signatures suggesting a low temperature anomaly in the electronic state. Magnetic susceptibility shows an upturn below about 30 K[5]. Such an upturn would be attributed to the effect of paramagnetic impurities. However, the present anomaly is robust even in high magnetic field. Peculiar temperature dependence of the nuclear relaxation rate below about 30 K strongly suggest a recovery of density of states near Fermi level. [8] The analysis of the low temperature behavior to understand those anomalies is left for future study.

4. Summary

We investigated magnetoresistance and Hall effect on URhIn₅ both in paramagnetic and antiferromagnetic states. In contrast to the small Hall coefficient in the paramagnetic state, a significant negative Hall coefficient was observed in the antiferromagnetic state, indicating relatively small carrier number. The observation suggests that Fermi surface is partially gapped at the antiferromagnetic transition. The two-band analysis gave a carrier number of 5.5 % per formula unit, in agreement with the dHvA study.

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