# Anomalous Hall effect in heavy fermion compounds $Ce_2MIn_8$ ($M$=Rh or Ir)

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**Abstract**

We have grown single crystals of heavy fermion $Ce_2MIn_8$ compounds and measured the magnetic susceptibility $\chi$ and Hall effect for these compounds in the temperature $T$ range 2–300 K. We found that the anomalous Hall coefficients $R_S$ of these compounds are described as $R_S \propto \chi$ at high temperatures, $R_S \propto \chi\rho$ at T nearly equal to the kondo temperature and $R_S \propto \rho^2$ at lowest temperature region. Such behavior of $R_S$ agrees with an universal temperature dependence of $R_S$ for heavy fermion materials.

*Key words:* heavy fermion; $Ce_2RhIn_8$; $Ce_2IrIn_8$; Hall effect

Recently a new heavy fermion superconducting compounds $CeMIn_5$ ($M$=Co, Rh Ir) has been discovered[1–3]. These materials crystallize in the quasi-two-dimensional tetragonal $HoCoGa_5$ structure and are built of alternating stacks of layers for $CeIn_3$ and $MIn_2$. A bilayer variants, $Ce_2MIn_8$, where 2 layers of $CeIn_3$ units are replaced for monolayer of $CeIn_3$ in $CeMIn_5$, are expected to becomes a superconductor under ambient or high pressures. Until now, however, $Ce_2RhIn_8$ and $Ce_2IrIn_8$ are known as antiferromagntic and paramagnetic heavy fermion materials, respectively[4–6].

To investigate a quasi-two-dimensionality in the electrical band structure of $R_2MIn_8$ compounds, we have measured the de Haas-van Alphen effect on $La_2RhIn_8$ and reported in [7]. In this paper we have measured the Hall effect and magnetic susceptibility of heavy fermion compounds $Ce_2MIn_8$ to elucidate electron scattering nature by Ce ions in these compounds

Single crystals of $R_2MIn_8$ were grown from an In flux starting from the initial compositions of $R$:$M$:In=2:1:10 by a similar method described in [7]. The crystal structure and phase purity were confirmed by an X-ray powder diffraction method. The obtained lattice parameters for both compounds agree with [5,6]. Measurement of Hall coefficient and electrical resistivity were made by a usual DC method. A SQUID magnetometer was used for magnetic susceptibility measurement.

Figure 1 shows the temperature $T$ dependence of the Hall coefficient $R_H$ for $Ce_2MIn_8$ ($M$=Rh, Ir) measured with magnetic field parallel to the $c$-axis. This figure contains the insets of the resistivity $\rho$ and susceptibility $\chi$ *vs* $T$. From the temperature dependence of $\rho$ we can confirm that $Ce_2RhIn_8$ and $Ce_2IrIn_8$ are heavy fermion materials with the Kondo temperatures of several tens of kelvins and nearly a hundred kelvin , respectively. The coherent state develops at $T_m \sim 5$ K for $Ce_2Rhin_8$ and $T_m \sim 50$ K for $Ce_2IrIn_8$. The susceptibility is found to be well described by the Curie-Weiss law for both field directions at $T \geq 150K$ with the effective Bohr magneton value of 2.54 for $Ce^{3+}$ ion. At $T \leq 100$ K, the susceptibility deviate downward from the Curie-Weiss low owing to the Kondo effect. The $\chi$ curve of $Ce_2RhIn_8$ shows a kink at about 3 K. this temperature corresponds to the Néel temperature.

For a paramagnetic material, the Hall coefficient is given by

$$R_H = R_0 + 4\pi\chi R_S \quad (1)$$

where $R_0$ and $R_S$ are is the normal and anomalous

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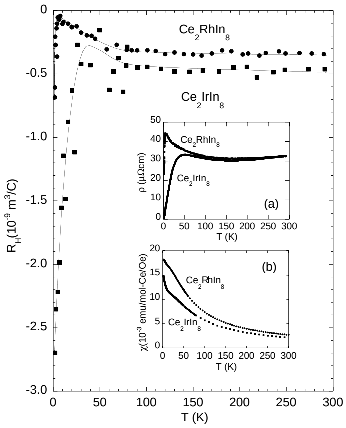


Fig. 1. The temperature $T$ dependence of the Hall coefficient $R_H$ for $Ce_2RhIn_8$ and $Ce_2IrIn_8$ measured with fields parallel to the $c$-axis. The insets shows the resistivity $\rho$ and the susceptibility $\chi$ as a function of $T$.

Hall coefficients, respectively. To see $\chi$ dependence of $R_H$ we plot $R_H$ as a function of $\chi$ in figure 2(a). From this figure we can see that the data of $R_H$ for $\geq 100$ K are well described by equation (1) and we obtained the values of $R_0 = -0.36 \times 10^{-9}$ m$^3$/C and $R_S = 0.47 \times 10^{-9}$ m$^3$/C.

Figure 2(a), however, shows that the $R_H$ values are enhanced and deviate from the prediction of equation (1) at large $\chi$ values. We attribute this deviation to the Kondo effect. According to the theory of the Hall effect[8] for a heavy fermion material, the anomalous Hall coefficient arises from resonant skew scattering by Ce ions and is given by, for $T \geq T_m$ region,

$$R_H = R_0 + \gamma\tilde{\chi}\rho_{mag} \tag{2}$$

where $\tilde{\chi}$ is the susceptibility divided by the Curie constant, $\rho_{mag}$ the resistivity due to magnetic scattering and $\gamma$ a constant. Now we plot the data for $T_m \leq T \leq 100$ K as a function of $\tilde{\chi}\rho_{mag}$ in figure 2(b) for $Ce_2IrIn_8$. To get the value of $\rho_{mag}$ we subtracted a phonon part of $\rho$ for $La_2RhIn_8$ from $\rho$ of $Ce_2RhIn_8$. Figure 2(b) sows that $R_H$ is well described by equation (2), suggesting that the enhancement of $R_H$ from equation (1) is due to the Kondo effect.

The high temperature data of $R_H$ for $Ce_2IrIn_8$ are found to fit well to equation (1), as shown in figure 2(a). We obtain the values of $R_0 = -0.49 \times 10^{-9}$m$^3$/C and $R_S = 0.53 \times 10^{-9}$m$^3$/C. We note that the $R_0$ and $R_S$ values of $Ce_2Rhin_8$ and $Ce_2IrIn_8$ are nearly same. This indicate that band structures for both compounds are very similar and electron scattering by Ce magnetic ion take places by the same extent. Since the scattering of data for $Ce_2IrIn_8$ at about 50 K is somewhat large, we can not compare the $R_H$ data with the theoretical prediction for Kondo effect. But at the lowest temperature region $R_H$ is represented by $R_H \propto \rho^2$. This dependence agree with the theoretical prediction of $R_H$ for $T \leq T_m$ [9].

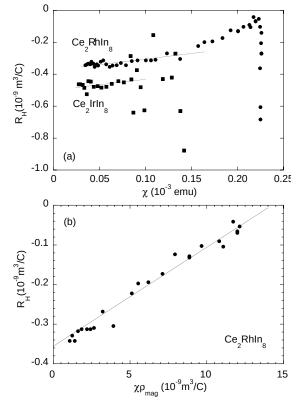


Fig. 2. The Hall coefficient $R_H$ as a function of susceptibility $\chi$ (a) and as a function of $\tilde{\chi}\rho_{mag}$ (b) for $Ce_2RhIn_8$ and $Ce_2IrIn_8$. Here $\tilde{\chi}$ is the normalized susceptibility and $\rho_{mag}$ the resistivity due to magnetic scattering.

In summary, we have measured the Hall coefficient for heavy fermion compounds $Ce_2RhIn_8$ and $Ce_2IrIn_8$ and found that the gross features of $R_H$ are well explained by an universal temperature dependence of $R_H$ for heavy fermion materials.

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