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## ANOMALOUS HALL COEFFICIENT IN Ce AND U COMPOUNDS

Y. Ōnuki <sup>(1)</sup>, T. Yamazaki <sup>(1)</sup>, T. Omi <sup>(1)</sup>, I. Ukon <sup>(1)</sup>, A. Kobori <sup>(1)</sup>, T. Komatsubara <sup>(1)</sup>,  
A. Umezawa <sup>(2)</sup>, W. K. Kwok <sup>(2)</sup>, G. W. Crabtree <sup>(2)</sup> and D. G. Hinks <sup>(2)</sup>

<sup>(1)</sup> Institute of Materials Science, University of Tsukuba, Tsukuba, Ibaraki 305, Japan

<sup>(2)</sup> Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439, U.S.A.

**Abstract.** – The Hall coefficient of Ce, U compounds and  $Ce_xLa_{1-x}Cu_6$  is presented.

The f electrons of the Ce and U compounds show a wide variety of behavior including Pauli itinerance, spin fluctuation, intermediate valence, heavy fermion and localized state. The Hall effect is a good experimental method to detect the f electron behavior. We report the temperature dependence of Hall coefficient of Ce, U compounds and  $Ce_xLa_{1-x}Cu_6$ .

First we show in figures 1 and 2 the temperature dependence of Hall coefficient of Ce and U compounds, respectively. These figures help us to easily understand the f electron behavior and the magnitude of the Hall coefficient for each substance and to recognise the large positive Hall coefficient in heavy fermion compound, although some of the results were already reported [1-3].

When the f electron shows Pauli itinerance, the Hall coefficient is temperature-independent as well as that of a simple metal.  $CeRu_2$ ,  $UIr_3$  and  $U_6Fe$  are applied to this group.

$CeSn_3$  and  $USn_3$  show a slight decrease of Hall coefficient with decreasing temperature. These substances are classified as the mixed valent or spin fluctuating materials.

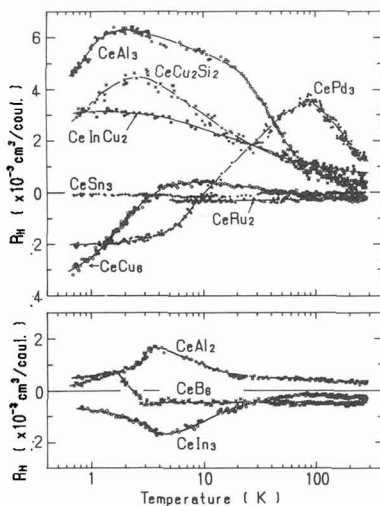


Fig. 1. – Hall coefficient of Ce compounds.

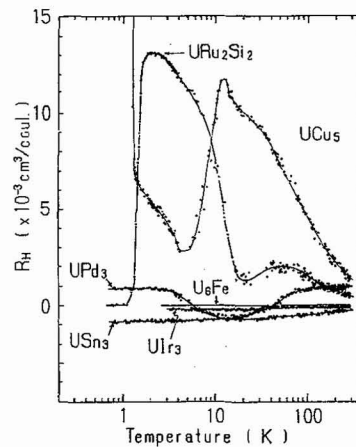


Fig. 2. – Hall coefficient of U compounds.

The heavy fermion substances such as  $CePd_3$ ,  $CeInCu_2$ ,  $CeCu_2Si_2$ ,  $CeAl_3$  and  $CeCu_6$  show an extremely large Hall coefficient in magnitude. The low temperature Hall coefficient of these heavy fermion compounds is sample-dependent. In  $CePd_3$  and  $CeCu_6$ , it changes the sign from positive to negative, while it is positive in  $CeInCu_2$ ,  $CeCu_2Si_2$  and  $CeAl_3$ . Probably it depends on the nature of carriers with heavy masses which are formed below 1 K.

The Hall coefficient of  $URu_2Si_2$  and  $UCu_5$  is also classified as the heavy fermion compound, although they are spin density wave antiferromagnets at low temperatures. The Néel temperatures are 17.4 K and 15.0 K, respectively. In the figure the Hall coefficient in  $URu_2Si_2$  increases by twenty times below the Néel temperature because the antiferromagnetic gap is opened due to the formation of spin density wave. A steep decrease of Hall coefficient below 1.5 K is due to superconductivity. On the other hand, intensive carrier reduction is not found in  $UCu_5$  just below the Néel temperature, but is observed below 1.3 K.

The Hall coefficients of the antiferromagnetically ordered Kondo substances such as  $CeAl_2$ ,  $CeIn_3$  and  $CeB_6$  are not simple. The anomalous part of the Hall coefficient is positive in  $CeAl_2$ , negative in  $CeIn_3$  and

zero in  $\text{CeB}_6$  in the paramagnetic region. Here, the Néel temperatures are 3.8 K, 10 K and 2.3 K, respectively.

The Hall coefficient of  $\text{UPd}_3$  is also unusual. It decreases with decreasing temperature, but increases below the quadrupolar ordering, 7 K, possessing the room temperature value below 3 K.

For these Ce and U compounds, the theoretical analyses have been tried [1, 2]. One is to apply the phenomenological Hall coefficient;  $R_H = R_0 + 4\pi R_s \chi$ . Here,  $R_0$  is the normal Hall coefficient,  $R_s$  temperature-independent and  $\chi$  the magnetic susceptibility. The other is to apply the recent skew scattering theory for Kondo impurities [4];  $R_H = R_0 + \gamma_1 \rho_m \tilde{\chi}$ . Here,  $\gamma_1$  is temperature-independent,  $\rho_m$  the magnetic resistivity,  $\tilde{\chi} = \chi/C$  and  $C$  the Curie constant. This theory is well fitted to the heavy fermion compounds of  $\text{CeAl}_3$  and  $\text{CeRu}_2\text{Si}_2$  at high temperatures [2], and explains the reason why the Hall coefficient of heavy fermion compound is so large in magnitude. Namely, it is mainly due to the large  $\rho_m$ -value.

We have also applied this theory to  $\text{Ce}_x\text{La}_{1-x}\text{Cu}_6$  which reveals the smooth transition from the impurity Kondo state to the Kondo lattice one [5], as shown in figure 3. The fitting procedure is the same with reference [2], and the experimental values of  $\rho_m$  and  $\tilde{\chi}$  in reference [5] are used. The theoretical curves shown by the solid lines are well fitted to the experimental data above 20 K. We stress that the phase shift  $\delta_2$  in  $\gamma_1$  ( $= -(7/15)g\mu_B k_B^{-1} \cos \delta_2 \sin \delta_2$ ) is  $-0.02$ , independent of the Ce concentration. This means that the dense Kondo system of  $\text{Ce}_x\text{La}_{1-x}\text{Cu}_6$  is the same with the dilute Kondo system in this temperature region and the impurity theory is well applied to the Kondo lattice one when the temperature is enough higher than the Kondo temperature of about 4 K. The behavior at low temperatures is not simple and is left to the future analysis.

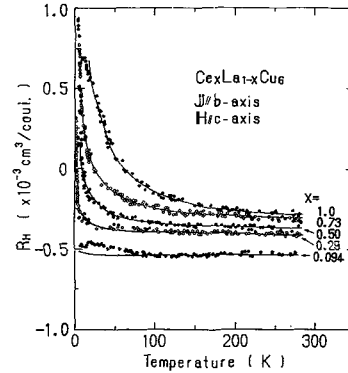


Fig. 3. - Hall coefficient of  $\text{Ce}_x\text{La}_{1-x}\text{Cu}_6$ . The theoretical curves are shown by the solid lines.

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