Hall effect in the $CeAl_3$ Kondo lattice in the coherent regime

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A sharp decrease has been found in the Hall coefficient $R_H(T)$ as the temperature is lowered in the interval $0.2 < T < 4$ K in the $CeAl_3$ Kondo lattice. A disruption of the periodicity of the Ce^{3+} Kondo centers, which suppress this effect, indicates that the decrease in $R_H(T)$ is related to the establishment of a coherence of Kondo fluctuations in Kondo lattices.

1. Nonmagnetic Kondo lattices ($CeAl_3$, $CeCu_2Si_2$, $CeCu_6$, UBe_{13}, etc.[1]) exhibit many nontrivial low-temperature properties which are consequences of the presence of a narrow Abrikosov-Suhl resonance of huge amplitude in the electron state density near the Fermi energy ϵ_F (the width of this resonance is on the order of the Kondo temperature, $T_K \approx 10$ K). Associated with this resonance $g_R(\epsilon)$ are quasiparticles (heavy fermions) with an effective mass $m^* \sim (10^2 - 10^3)m_0$ (m_0 is the mass of the free electron), which have an extremely low degeneracy temperature and which determine the unusual superconducting properties of the compounds $CeCu_2Si_2$ and UBe_{13} (Ref. 1).

Several recent results indicate that in addition to T_K there is yet another characteristic energy, $T_{coh} \sim T_K/10$, in nonmagnetic Kondo lattices; this energy corresponds to the onset of coherence in the scattering by magnetic ions. At $T < T_{coh}$, the resistance in the $CeAl_3$ and $CeCu_2Si_2$ nonmagnetic Kondo lattices decreases in accordance with[2] $\Delta\rho \sim T^2$; the Seebeck coefficient $S(T)$ changes sign; the sign of the thermal expansion coefficient $\alpha(T)$ changes[4]; and a maximum appears on the $C/T = f(T)$ curve (C is the heat capacity).[5] Since the value of C/T is proportional to the state density $g(\epsilon_F)$, the decrease in C/T indicates that a pseudogap may form at the Fermi level at the transition to the coherent regime.[5,6]

An earlier study[7] of the Hall coefficient of the $CeAl_3$ system revealed an anomalous increase in the Hall coefficient R_H with decreasing temperature in the range $3 < T < 150$ K. It is therefore interesting to determine the behavior $R_H(T)$ at lower temperatures, at which anomalies in C/T, $S(T)$, $\rho(T)$, and $\alpha(T)$ were found in $CeAl_3$.

In this letter we report a study of the behavior $R_H(T)$ of the nonmagnetic Kondo lattices in $CeAl_3$ and the solid solution $Ce_{0.8}La_{0.2}Al_3$ in the temperature interval $0.2 < T < 4$ K. Our results show, for the first time, that the anomalies in the Hall emf of a nonmagnetic Kondo lattice at ultralow temperatures are suppressed by a disruption of the periodicity in the arrangment of Kondo centers.

2. Measurements of the temperature and field dependence of the Hall resistance ρ_H of polycrystalline $CeAl_3$ and $Ce_{0.8}La_{0.2}Al_3$ samples $0.2 \times 2 \times 5$ mm in size, annealed for 200 h, were carried out in a computer-controlled apparatus using a ^3He–^4He

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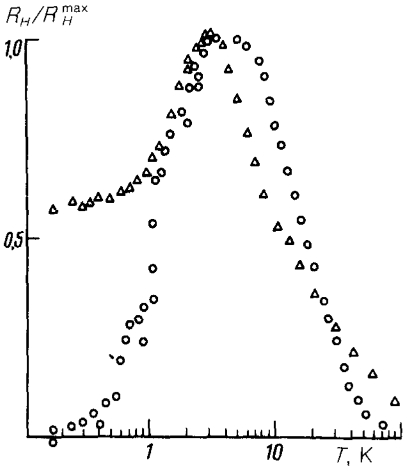

FIG. 1. The temperature dependence $R_H(T)/R_H^{max}$ for $CeAl_3$ (O) and $Ce_{0.8}La_{0.2}Al_3$ (△).

dissolution refrigerator. The field dependence of ρ_H was determined for two directions of the magnetic field H. To eliminate the induction emf, we took an average over the curves recorded as the magnetic field was turned on and off.

3. The temperature dependence $R_H(T)/R_H^{max}$, (Fig. 1) measured in a magnetic field $H = 30$ kOe is very nonmonotonic: $R_H(T)$ has a maximum near $T = T_{max} = 4$ K and then falls off sharply. On the field dependence $\rho_H(H)$ of $CeAl_3$ we find a maximum, which shifts down the magnetic-field scale with decreasing temperature (Fig. 2). For $T = 0.24$ K the $\rho_H(H)$ curve is a line which coincides within 1% of R_H^{max} with the abscissa.

The replacement of some of the Kondo centers—Ce^{3+} ions—by nonmagnetic La^{3+} ions induces an appreciable change in the temperature and field dependence of

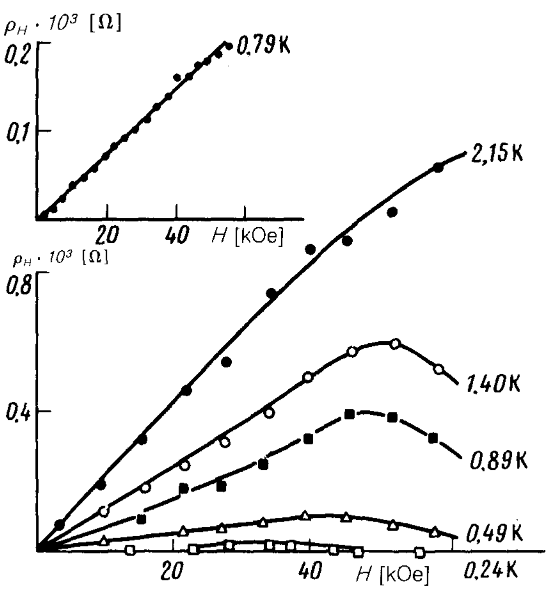

FIG. 2. Field dependence of the Hall resistance, $\rho_H(H)$, of $CeAl_3$ at various temperatures. The inset shows the field dependence $\rho_H(H)$ for $Ce_{0.8}La_{0.2}Al_3$ at $T \simeq 0.79$ K.

the Hall emf at $T < 1$ K: As the temperature is reduced in $Ce_{0.8}La_{0.2}Al_3$, in contrast with the situation in $CeAl_3$ (Fig. 1), the Hall coefficient decreases by about 40% of R_H^{max}. The field dependence $\rho_H(H)$ of $Ce_{0.8}La_{0.2}Al_3$ becomes linear up to $H = 60$ kOe (see the inset in Fig. 2).

4. Winzer[8] has suggested that the decrease of $R_H(T)$ at $T < T_{coh}$ might be interpreted as the result of a decrease in the contribution to $R_H(T)$ from asymmetric scattering[9] due to the freezing of the phonons which are responsible for the transitions between states with different orbital angular momenta. The results of the present study show that the decrease in $r_H(T)$ at $T < T_{coh}$ cannot be explained by this model. A disruption of the periodicity in the arrangement of Kondo centers could have only a negligible effect on the nature of the asymmetric scattering itself. On the other hand, the experimental dependence $R_H(T)$ is extremely different in the cases of $CeAl_3$ and $Ce_{0.8}La_{0.2}Al_3$. Furthermore, a calculation of the Hall mobility $\mu_H(T) = R_H/\rho$ shows that $\mu_H(T)$ remains essentially constant in $Ce_{0.8}La_{0.2}Al_3$ at $T < 4$ K and tends towards zero in $CeAl_3$.

Therefore, the most likely reason for the decrease in the Hall coefficient is the onset of coherence in the scattering in the periodic system of Kondo centers in nonmagnetic Kondo lattices.

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