HALL EFFECT AND SKEW SCATTERING IN MAGNETIC KONDO-LATTICE $CeAl_2$*

N.E. Sluchanko, A.V. Bogach, V.V. Glushkov, S.V. Demishev

General Physics Institute of RAS, 38 Vavilov str., Moscow 119991, Russia

G.S. Burkhanov, and O.D. Chystyakov

Institute of Metallurgy and Material Science of RAS
49 Leninskii Prospect, Moscow 119991, Russia

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A wide temperature range (1.8–300 K) Hall coefficient $R_{\rm H}$ measurements have been carried out on a high quality polycrystalline samples of a magnetic Kondo-lattice $CeAl_2$. The investigation of angular and magnetic field (up to 80 kOe) dependencies of the Hall coefficient and magnetoresistance in paramagnetic and modulated antiferromagnetic (AFM) phases of $CeAl_2$ allows to distinguish between skew scattering and anomalous magnetic contributions. A complicated activation type behavior of the skew scattering component is found in this intermetallic compound for the first time. The anomalous magnetic Hall effect is caused by several magnetic phases on H–T diagram of $CeAl_2$.

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An anomalous transport properties and especially unusual Hall effect have been observed in a number of heavy fermion (HF) systems. Very large and positive Hall coefficient observed in various experiments has been qualitatively explained in the framework of skew scattering models proposed in [1, 2] where the asymmetry of the charge carriers' scattering results from the resonance of conduction electrons with f-levels orbitally split by an applied field [2].

Here last results of Hall coefficient and magnetoresistance measurements are presented for the "coexistence compound" — magnetic Kondo-lattice $CeAl_2$. The issue of this study was twofold — *(i)* to verify the validity of the skew scattering models [1, 2] and *(ii)* to investigate in more details the

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mysterious magnetic phase transitions [3, 4] in $CeAl_2$ with the help of high precision transport measurements. The experiments have been carried out on high quality polycrystalline samples of this cubic *C15* Laves-phase material in a wide temperature range 1.8–300 K in magnetic fields up to 80 kOe. The angular dependencies of Hall resistivity $R_\mathrm{h}(\varphi)$ have been measured in $CeAl_2$ at liquid helium temperatures above and below the antiferromagnetic phase transition at $T_\mathrm{N} \approx 3.85$ K. The sample was rotated in magnetic field $\boldsymbol{H}$ around the dc-current $\boldsymbol{I}$ axis in transversal ($\boldsymbol{I} \perp \boldsymbol{H}$) geometry. It was found [5] that a single harmonic behavior of the Hall resistivity $R_\mathrm{h}(\varphi)$ is destroyed in magnetic fields $H \geq 3$ kOe and even harmonics appear to contribute in total signal $R_\mathrm{h}(\varphi)$. To verify the effects of magnetoresistance contribution in the Hall resistivity the magnetoresistance measurements have been also carried out. The results obtained in these simultaneous experiments allowed to exclude the Hall contacts asymmetry from the factors produced the higher harmonics generation in the Hall signal.

The data analysis in terms of expression

$$R_h(H_0, T_0, \varphi) = R_0 + R_{\mathrm{h}1}\sin(\varphi - \varphi_{01}) + R_{\mathrm{h}2}\sin 2(\varphi - \varphi_{02}) \qquad (1)$$

allowed to deduce the Hall resistivities $R_{\mathrm{h}1}$ and $R_{\mathrm{h}2}$ in Eq. (1) and hence the anomalous components R_H^a and R_H^{am} of Hall effect. Temperature and magnetic field dependencies of R_H^a and R_H^{am} parameters are shown in Fig. 1. Among these two contributions the large anomalous positive component R_H^a (skew scattering contribution [1, 2]) demonstrates a broad maximum around $T \approx 4$ K (Fig. 1(a)) which is depressed drastically (by a factor of 3) in magnetic field $H \approx 80$ kOe (Fig. 1(b)). The decrease of magnitude of R_H^a in magnetic field depends only slightly from the temperature in the interval 3.4 K $< T_\mathrm{N} <$ 4.2 K in the vicinity of the broad maximum of R_H^a. Such a strong $R_\mathrm{H}^a(H)$ dependence can be attributed to the depression of the Kondo-compensation mechanism in magnetic field. Indeed, in the case of $CeAl_2$, where the Kondo temperature is found to be $T_\mathrm{K} \approx 5$ K [3], one can expect an essential decrease of amplitude of the Abrikosov–Suhl resonance in moderate magnetic field $H \leq 80$ kOe resulting to the reduction of the R_H^a component [1].

The most striking feature of the skew scattering component temperature dependence $R_\mathrm{H}^a(T)$ in this intermetallic compound is a complicated *activation type behavior*. The plot $\log(R_\mathrm{H}^a e) = f(1/T)$ (Fig. 2(a)) allows to establish two activation processes in transport with the energies $E_{a1} = 30.3 \pm 0.8$ K (in the interval 70–300 K) and $E_{a2} = 9.2 \pm 0.1$ K (10–40 K). Additionally, the reciprocal Hall coefficient to the resistivity ratio of charge carriers $\mu^{-1}(T) = \rho(T)/R_\mathrm{H}(T)$ (Fig. 2(b)) is characterized by Curie–Weiss type behavior $\mu^{-1}(T) \sim \chi^{-1}(T) \sim (T + \Theta_i)$ in these intervals with $\Theta_1 = -350 \pm 20$ K and $\Theta_2 = -7.5 \pm 0.5$ K correspondingly. Among these two findings the first

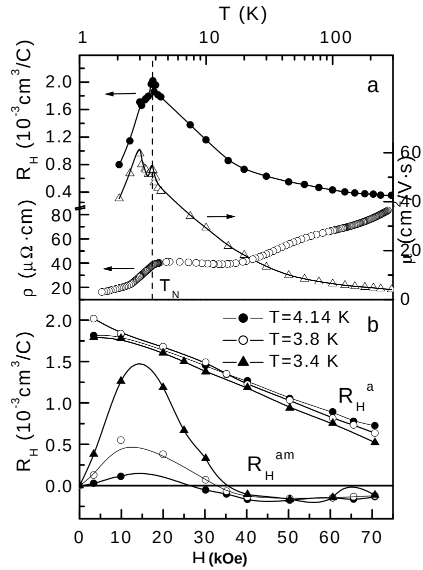

Fig. 1. (a) Temperature dependencies of the Hall coefficient, resistivity and Hall coefficient to resistivity ratio. (b) Anomalous components of the Hall coefficient R_{H}^{a} and R_{H}^{am} *versus* applied magnetic field.

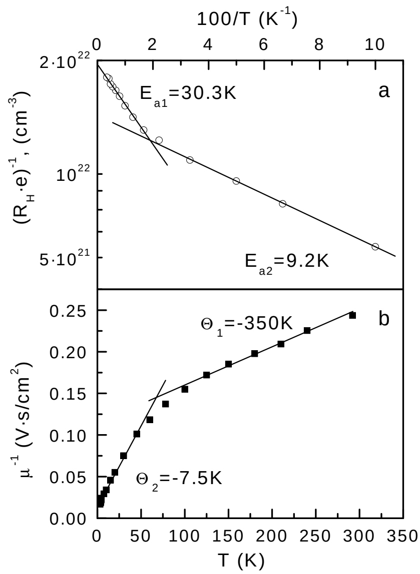

Fig. 2. Reciprocal (a) Hall coefficient $(R_{\mathrm{H}}^{a} e)^{-1} = f(1/T)$ and (b) Hall coefficient to the resistivity ratio $\mu_{\mathrm{H}}^{-1}(T)$ temperature dependencies.

one is out of the conclusions of skew scattering models [1, 2], while the analytical dependence $\mu(T) \sim \chi(T)(1 - \chi(T))$ predicted in [1] for temperature range $T \gg T_{\rm K} \approx 5$ K is very similar to that one observed in this study (Fig. 2(b)). However, to analyze in detail the data of present study one needs also to estimate the effects of real crystal electric fields in $\rm CeAl_2$ ($\Delta_{CF1} \approx 100$ K [3]) additionally to the approaches developed in [1, 2].

The anomalous magnetic contribution in the Hall coefficient $R_{\rm H}^{am}$ is characterized by *(i)* a narrow maximum at $T = T_{\rm N} \approx 3.85$ K (Fig. 1(a)) and *(ii)* a non-monotonous behavior of $R_{\rm H}^{am}$ (deduced from the second harmonic component $R_{\rm h2}$ in Eq. (1)) in the magnetic field below 40 kOe (Fig. 1(b)). A maximum of the anomalous magnetic Hall coefficient $R_{\rm H}^{am}(H)$ is observed at $H_m \approx 15$ kOe, moreover, the amplitude of this peak increases dramatically when the temperature decreases below $T_{\rm N}$ (Fig. 1(b)). Following to the arguments of the authors [6] the $R_{\rm H}^{am}(H)$ anomaly can likely be attributed to the AFM-domains reorientation process at liquid helium temperatures.

Another interesting feature of the $R_{\rm H}^{am}(H)$ dependencies is the change of sign of the second harmonic which occurs in the magnetic fields interval 30–40 kOe (Fig. 1(b)). It is important to stress here that the $R_{\rm H}^{am}(H)$ sign inversion points $H_{\rm inv}$ are placed just above the AFM phase boundary and especially for the cases of $T = 4.14$ K and $T = 3.8$ K can be attributed to "the unknown magnetic phases" [3–6] on the H–T phase diagram of $\rm CeAl_2$. Thus, the last finding contributes in favor of conclusion [3,6] of a rather complicated magnetic behavior with short range ferromagnetic correlations which have been established in $\rm CeAl_2$ just above the AFM phase boundary. Moreover, to support the arguments of [3] in favor of two magnetic phase transitions in $\rm CeAl_2$ the Hall coefficient to the resistivity ratio $\mu(T)$ demonstrates two narrow peaks at 3.85 K and 3.0 K (Fig. 1(a)). To clarify in more details the H–T magnetic phase diagram in this "coexistence" compound the anomalous transport measurements are in progress now.

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