Hall effect anomalies in Kondo-lattice $CeAl_2$

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Abstract

Anomalous Hall effect in paramagnetic and modulated antiferromagnetic (AFM) phases of a Kondo-lattice $CeAl_2$ has been studied in a wide range of temperatures (1.8-300K) and magnetic fields (up to 80 kOe). It was shown that the large anomalous skew scattering component R_H^a has a broad maximum around $T\approx$4K depressing by a factor of 3 in $H\approx$80 kOe. A non-monotonous behavior of anomalous magnetic component R_H^{am} in magnetic fields below 40 kOe which also demonstrates a narrow peak of $R_H^{am}(T)$ at $T=T_N\approx$3.85K is likely to be attributed to the AFM-domains reorientation process at liquid helium temperatures. The problem of two magnetic phase transitions and complicated activation type behavior of R_H^a in this intermetallic "coexistence compound" are discussed.

Key words: spin fluctuations, Kondo-lattice, antiferromagnetism

An anomalous transport properties and especially unusual Hall effect have been observed in a number of Kondo-lattice compounds and qualitatively explained in the framework of skew scattering models [1,2]. Here the 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 in details the validity of the skew scattering models [1,2] and (ii) to investigate the 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 wide temperature range 1.8-300K in magnetic fields up to 80 kOe. To measure the angular dependencies of Hall resistivity and magnetoresistance in $CeAl_2$ the sample was rotated in magnetic field $\boldsymbol{H}$ around the 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 is destroyed in magnetic fields $H\geq$3 kOe and even harmonics appear to contribute

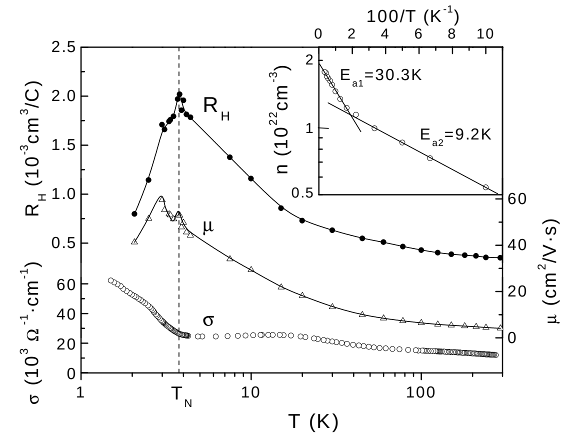

Fig. 1. Temperature dependencies of the Hall coefficient, conductivity and mobility in $CeAl_2$. Inset shows the activation behavior of the reciprocal Hall coefficient $n=(R_H^a e)^{-1}$.

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in total Hall signal. To eliminate the effects of magnetoresistance contribution in the Hall resistivity the magnetoresistance measurements have been also carried out. The data analysis [5] allowed to deduce the anomalous components R_H^a and R_H^{am} of the Hall effect in $CeAl_2$. Temperature and magnetic field dependencies of R_H^a and R_H^{am} parameters are shown in Figs.1-2. 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) which is depressed drastically (by a factor of 3) in magnetic field $H \approx 80$ kOe (Fig.2). The decrease of magnitude of R_H^a in magnetic field depends only slightly from the temperature in the interval 3.4K$<T_N<$4.2K in the vicinity of the broad maximum of R_H^a. Such a strong $R_H^a(H)$ 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 $T_K \approx 5$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 $R_H^a(T)$ in this intermetallic compound is a complicated ***activation type behavior***. The plot $\log(R_H^a e)^{-1} = f(1/T)$ (inset of Fig.1) allows to establish two activation processes in transport with the energies $E_{a1}=30.3\pm0.8$K (in the interval 70-300K) and $E_{a2}=9.2\pm0.1$K (10-40K). Additionally, the reciprocal mobility of charge carriers $\mu^{-1}(T)=(\sigma(T)R_H(T))^{-1}$ (inset of Fig.2) is characterized by Curie-Weiss type behavior $\mu^{-1}(T)\sim\chi^{-1}(T)\sim(T+\Theta_i)$ in these intervals with Θ_1=-350±20K and Θ_2=-7.5±0.5K correspondingly. Among these two findings the first one is out of the conclusions of the skew scattering models [1,2], while the analytical dependence $\mu(T)\sim\chi(T)(1-\chi(T))$ predicted in [1,2] for temperature range $T \gg T_K \approx 5$K is very similar to that one observed in this study. However, to analyze in detail the data of Figs.1-2 one needs also to estimate the effects of real crystal electric fields in $CeAl_2$ ($\Delta_{CF1} \approx 100$K [3]) additionally to approaches [1,2].

The anomalous magnetic contribution in the Hall coefficient R_H^{am} is characterized by (i) a narrow maximum at $T=T_N \approx 3.85$K (Fig.1) and (ii) a non-monotonous behavior of R_H^{am} in the magnetic field below 40 kOe (Fig.2). A maximum of the anomalous magnetic Hall coefficient $R_H^{am}(H)$ is observed at $H_m \approx 15$ kOe, moreover, the amplitude of this peak increases dramatically when the temperature decreases below T_N (Fig.2). Following to the arguments suggested in [6] the $R_H^{am}(H)$ anomaly can likely be attributed to the AFM-domains reorientation process at liquid helium temperatures.

Another interesting feature of the $R_H^{am}(H)$ dependencies is the change of sign which occurs in the magnetic fields interval 30-40 kOe (Fig.2). It is important to stress here that the $R_H^{am}(H)$ sign inversion points are placed just above the AFM phase boundary and especially for the cases of T=4.14K and T=3.8K can be attributed to "the unknown magnetic phases" [3–6] on the $H-T$ phase diagram of $CeAl_2$. 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 $CeAl_2$ just above the AFM phase boundary. Moreover, to support the arguments of [3] in favor of two magnetic phase transitions in $CeAl_2$ the mobility $\mu_H(T)$ demonstrates two narrow peaks at 3.85K and 3.0K (Fig.1). To clarify in more details the H-T magnetic phase diagram in this "coexistence" compound the anomalous transport measurements are in progress now.

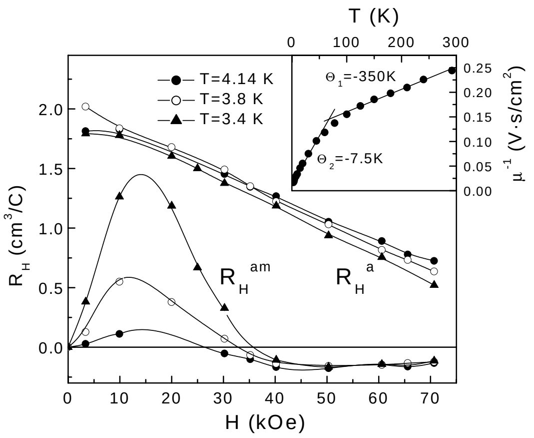

Fig. 2. Anomalous components of the Hall coefficient R_H^a and R_H^{am} versus applied magnetic field in $CeAl_2$. Inset shows the reciprocal mobility $\mu_H^{-1}(T)$ temperature dependence.

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