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 \(R_{\text{aH}}\) has a broad maximum around \(T \approx 4\)K depressing by a factor of 3 in \(H \approx 80\) kOe. A non-monotonous behavior of anomalous magnetic component \(R_{\text{am}}\) in magnetic fields below 40 kOe which also demonstrates a narrow peak of \(R_{\text{am}}\) at \(T \approx 3.85\)K 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 \(R_{\text{aH}}\) 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 \(H\) around the current \(I\) axis in transversal \((I \perp H)\) 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 significantly.
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 \( R_{H}^{m} \) and \( R_{H}^{am} \) of the Hall effect in CeAl\(_2\). Temperature and magnetic field dependences of \( R_{H}^{m} \) and \( R_{H}^{am} \) parameters are shown in Figs.1-2. Among these two contributions the large anomalous positive component \( R_{H}^{m} \) (skew scattering contribution [1,2]) demonstrates a broad maximum around \( T \approx 4K \) (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 \( R_{H}^{m} \) 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 \( R_{H}^{m} \). Such a strong \( R_{H}^{m} \) (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 \( T_K \approx 5K \) [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 \( R_{H}^{m} \) component [1].

The most striking feature of the skew scattering component temperature dependence \( R_{H}^{am}(T) \) in this intermetallic compound is a complicated activation type behavior. The plot \( \log(R_{H}^{am}e) = f(1/T) \) (inset of Fig.1) allows to establish two activation processes in transport with the energies \( E_{1} \approx 30.3\pm 0.8K \) (in the interval 70-300K) and \( E_{2} = 9.2\pm 0.1K \) (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 \( \mu^{-1}(T) \sim \chi^{-1}(T) \sim (T+\Theta_{1}) \) in these intervals with \( \Theta_{1} = -350\pm 20K \) and \( \Theta_{2} = -7.5\pm 0.5K \) correspondingly. Among these two findings the first one is out of the conclusions of the skew scattering models [1,2], while the analytical dependence \( \mu^{-1}(T) \sim (1 - \chi(T)) \) predicted in [1,2] for temperature range \( T \gg T_K \approx 5K \) 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\(_2\) (\( \Delta_{CEF} \approx 100K \) [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 \( T = T_N \approx 3.85K \) (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 \( H_{am} \approx 15 \) 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 mag-