Magnetic Field Enhancement of the Hall Effect in Dilute Magnetic System La$_{1-x}$Ce$_x$B$_6$ ($x \leq 0.1$)

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Magnetic field dependences of the Hall coefficient $R_H$ and resistivity have been studied in detail for dilute magnetic compounds La$_{1-x}$Ce$_x$B$_6$ ($x \leq 0.1$) at temperatures 1.8–300 K. It was established that the regime of weak localization of charge carriers, which was observed in these heavy fermion systems below 30 K destroys gradually in magnetic field up to 8 T. Moreover, in addition to the strong negative magnetoresistance ($\Delta \rho/\rho \approx 80\%$) a drastic enhancement of the negative Hall coefficient in magnetic field ($\Delta R_H/R_H \approx 50\%$) has been deduced at liquid helium temperatures. The results of comprehensive analysis contradict the predictions of Kondo-impurity approach for this archetypal strongly correlated electron system in the dilute impurity limit. An alternative interpretation of La$_{1-x}$Ce$_x$B$_6$ properties is developed on the basis of spin-polaron approach, Pauli paramagnetism and the density of states renormalization effects at low temperatures.

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1. Introduction

Recent discovery of quantum critical behavior in heavy fermion solid solutions La$_{1-x}$Ce$_x$B$_6$ in the range of $x \leq 0.6$ [1] has brought renewed interest to study unusual properties of these strongly correlated electron systems. Authors in [1] interpreted the experimental results in frame of the Kondo-impurity approach and pointed out that special attention should be paid to the low concentration limit $x \leq 0.1$. At the same time the results of very recent research of resistivity, thermopower, low field Hall coefficient and magnetic susceptibility studies of La$_{1-x}$Ce$_x$B$_6$ ($x \leq 0.1$) [2] contradict the predictions of Kondo-impurity approach for these archetypal strongly correlated electron systems in low impurity limit. Contrarywise, all experimental results obtained in [2] for cerium based magnetic systems La$_{1-x}$Ce$_x$B$_6$ ($x \leq 0.1$) were successfully interpreted in terms of the spin-polaron approach, developed earlier for the dense magnetic system CeB$_6$ [3]. To verify this approach for dilute compounds La$_{1-x}$Ce$_x$B$_6$ ($x \leq 0.1$) in detail it is promising to investigate charge transport anomalies in La$_{1-x}$Ce$_x$B$_6$ in strong magnetic fields.

2. Results and discussion

To shed more light on the nature of many-body states in the metallic La$_{1-x}$Ce$_x$B$_6$ matrix, the precision measurements of magnetoresistance and Hall effect have been carried out on high-quality single crystals of dilute magnetic substitutional solid solutions La$_{1-x}$Ce$_x$B$_6$ ($x \leq 0.1$) in a wide temperature range 1.8–300 K in strong magnetic fields up to 80 kOe. The analysis of the resistivity behavior of La$_{1-x}$Ce$_x$B$_6$ ($x \leq 0.1$) in magnetic field reveals that the weak localization regime observed in these dilute magnetic systems at $T < 30$ K [2] depresses drastically with $H$ elevation above 20 kOe, resulting to the appearance of strong negative magnetoresistance ($\Delta \rho/\rho \approx 80\%$). Figure 1 shows typical magnetic field dependences of the magnetoresistance $\Delta \rho/\rho(H^2)$ for La$_{1-x}$Ce$_x$B$_6$ compounds with $x = 0.03$ and 0.1, correspondingly. The most appropriate interpretation of such negative quadratic magnetoresistance $-\Delta \rho/\rho \sim H^2$ (Fig. 1) was developed and verified earlier for dense mag-

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Fig. 2. Temperature dependences of the Hall coefficient \( R_H(T) \) of \( \text{La}_{1-x}\text{Ce}_x\text{B}_6 \) at different magnetic fields for \( x = 0.03 \) (a) and 0.1 (b).

Fig. 3. Magnetic field dependences of the Hall coefficient \( R_H(H) \) of \( \text{La}_{1-x}\text{Ce}_x\text{B}_6 \) at different temperatures in the range 2–50 K for \( x = 0.03 \) (a) and 0.1 (b).

netic system \( \text{CeB}_6 \) [3] within the framework of the Yosida approach [4], and seems to be efficient for dilute magnetic alloys \( \text{La}_{1-x}\text{Ce}_x\text{B}_6 \) as well.

Following to the Hall effect studies of \( \text{La}_{1-x}\text{Ce}_x\text{B}_6 \) in low magnetic fields [2] the investigation of the Hall coefficient was developed in present studies in the range \( H \leq 80 \) kOe. A strong enhancement of the Hall effect in magnetic field both for \( x = 0.03 \) (Fig. 2a, 3a) and 0.1 (Fig. 2b, 3b) at liquid helium temperatures was established evidently. The increase of the negative values of \( R_H(H) \) is almost linear in magnetic field (Fig. 3) and it reaches an amplitude \( \Delta R_H/R_H \approx 50\% \) when \( H \) increases up to 80 kOe at temperature \( T \approx 2 \) K. Resulting from the strong influence of magnetic field on the resistivity (Fig. 1, see also [2]) and on the Hall coefficient (Figs. 2, 3), a drastic elevation of the Hall mobility values \( \mu(H) = R_H(H)/\rho(H) \) is observed with an enhancement factor \( \mu(H)/\mu(0) = 5 \div 8 \) at 2 K in magnetic field of 80 kOe. It is needless to point out that these experimental results as well as the data of [2] obtained for \( \text{La}_{1-x}\text{Ce}_x\text{B}_6 \) solid solutions with \( x \leq 0.1 \) cannot be interpreted even qualitatively in terms of the skew-scattering and Kondo-lattice models [5, 6]. On the contrary, we suppose that present experimental data together with data of [2] retrieve sufficient interpretation in terms of the model, developed earlier for the dense magnetic system \( \text{CeB}_6 \) and based on spin-polaron approach, Pauli paramagnetism and DOS renormalization effects at low temperatures [3]. In the framework of this model both strong negative magnetoresistance (Fig. 1) and negative Hall coefficient enhancement in magnetic field (Figs. 2, 3) observed for archetypal strongly correlated electron systems \( \text{La}_{1-x}\text{Ce}_x\text{B}_6 \) in low impurity limit \( x \leq 0.1 \) may be explained in terms of the depression of many-body states (heavy fermions) and the polarization of 5d-states in the vicinity of Ce centers in the metallic matrix of these hexaborides.

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References