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Hall Effect in GdB_6

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The Hall effect of GdB_6 has been studied on high quality single crystals in the temperature range 2–150 K and in magnetic field of 1 T. The obtained data allow to detect anomalies in the antiferromagnetic (AF) phase including (i) a drastic enhancement of negative Hall coefficient below $T_{N1} \approx 15.5$ K and (ii) the appearance of an anomalous Hall effect at $T_{N2} \approx 4.7$ K. Possible scenarios of the AF ground state formation are discussed.

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1. Introduction

Gadolinium hexaboride (GdB_6) is thought to be a typical, spin only, Heisenberg magnet since the Gd^{3+} ion does not have the orbital degrees of freedom ($L = 0$, $S = 7/2$). However the magnetic structure of GdB_6, which is characterized by two successive first-order AFM transitions (AF(I) ordering below $T_{N1} \sim 15$ K, and AF(II) phase at temperatures $T < T_{N2} \sim 5$–10 K), is still a subject of discussion [1 – 8]. Recent studies of neutron diffraction and X-ray diffraction have shown that this compound exhibits a complex commensurate magnetic structure with a wave vector $\boldsymbol{k}_m = [1/4, 1/4, 1/2]$ at $T < T_{N1}$ [3 – 6]. Additionally, lattice distortions with $\boldsymbol{q}_1 = [1/2, 0, 0]$ and $\boldsymbol{q}_2 = [1/2, 1/2, 0]$ were observed in [3, 5] and allowed Amara et al. [7] to suggest the displacement waves scenario based on the coherent displacement of Gd^{3+} ions inside the boron cages below T_{N1}. At the same time the authors of [7] pointed at $T < T_{N2}$ to the existence of an additional satellite [1/4, 1/4, 1/2] identical to the magnetic wave vector $\boldsymbol{k}_m$, and they proposed a complex displacement scheme in the low AF(II) phase. In this respect the investigation of Hall effect is important to provide necessary information to describe the magnetic ground state of GdB_6 and its evolution.

2. Experimental details

GdB_6 high quality single crystal ($T_{N1} \approx 15.5$ K, $T_{N2} \approx 4.7$ K) was grown by the crucible-free inductive zone melting in argon gas atmosphere. The control of the sample quality was performed by electron microprobe and X-ray diffraction analysis. The angular dependences of Hall resistivity $\rho_H(\varphi)$ have been measured in the temperature range 2–150 K in magnetic field 1 T by stepwise sample rotation technique in fixed magnetic field, applied perpendicular to the rotation axis. The dc-current was applied along < 110 > axis, which was also the axis of sample rotation (see the inset in Fig. 1). The description of the experimental setup was presented previously in [9–10].

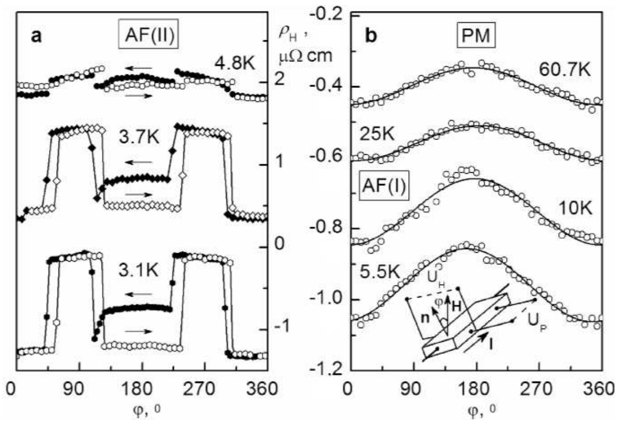

Fig. 1. The angular dependences of Hall resistivity of GdB_6, recorded in magnetic field $\mu_0 H = 1$ T at various temperatures in the range 2–150 K, corresponding to (a) AF(II), (b) AF(I) and PM phases. The solid lines display the approximation by the cosine-law (1). The inset in the panel (b) illustrates the scheme of the Hall effect measurements, $\mathbf{n}||$ < 001 >.

3. Experimental results and discussion

Figure 1 illustrates the angular dependences of Hall resistivity measured in low magnetic field $\mu_0 H = 1$ T for (a) AF(II), (b) AF(I) and PM phases of GdB_6. In the temperature interval 6 – 150 K, corresponding to PM and AF(I) phases the experimental data presented in Fig. 1b have been analyzed by the simple relation

$$\rho_H(\varphi) = \rho_{H0} + \rho_{H1} \cdot \cos(\varphi - \Delta\varphi), \quad (1)$$

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where ρ_{H0} is the constant bias term and ρ_{H1} is the main component of the Hall signal. A similar type of $\rho_H(\varphi)$ dependence was detected experimentally in PM phases of many AF metallic systems, including heavy fermionic $CeAl_2$, light hexaborides CeB_6 [9], PrB_6, NdB_6 [10] and dodecaborides RB_{12} (R-Lu, Ho, Er, Tm). Such behaviour of Hall resistivity can be attributed to the variation of the ***H*** vector's normal component in accordance with the harmonic law, when the sample is rotating in magnetic field.

The curves of $\rho(\varphi)$ measured in AF(I) state of GdB_6 show the absence of any appreciable contribution of a second harmonic $\sim \rho_{H2} \cdot \cos 2\varphi$ to the Hall signal (see Fig. 1b). This result is opposite to the case of RB_6 (R-Ce, Pr, Nd), where a significant component of second harmonic was detected in AF state (phase II for CeB_6) [9–10].

The most crucial changes in the form of angular dependences of Hall resistivity are observed upon the transition to the AF(II) phase at $T < T_{N2}$. In this state the $\rho_H(\varphi)$ curves demonstrate a meander-type behaviour with extended $\rho_H(\varphi) = const$ (plateau) regions, which are followed by periodical switching of the Hall resistivity in the narrow vicinity of $< 111 >$ directions (with a width smaller than 5°, see Fig. 1a). Moreover, hysteresis is also detected on $\rho_H(\varphi)$ curves at $T < T_{N2}$, measured for the sample rotated in opposite directions. Note that similar meander-type $\rho_H(\varphi)$ dependences were previously registered both in the AF state of CeB_6 [9] and in the low temperature micromagnetic phase of FeSi (see the discussion in [9]). The appearance of these singularities of the Hall resistance in combination with the drastic discrepancy of the $\rho_H(\varphi)$ data near 180° for different direction of rotation, indicate an emergence of anomalous component in the Hall resistance due to a appreciable magnetic contribution below T_{N2}.

The analysis of angular dependences of the Hall resistance based on Eq. 1 at 6 – 150 K allows to determine the shape of the $R_H(T) = \rho_{H1}(T)/H$ curve (see Fig. 2). In the temperature range 2 – 150 K the Hall coefficient is negative and R_H is virtually independent on temperature in the PM state, having a value $R_H \approx -4 \times 10^{-4}$ cm^3/C ($n/n_{4f} \sim 1$). This value is in agreement with results presented in [9–10] for light hexaborides RB_6 (R-La, Ce, Pr, Nd). The transition to AF(I) phase in GdB_6 is accompanied by a drastic decrease of $R_H(T)$ down to -6.7×10^{-4} cm^3/C at 6 K. According to the approach presented in [9–10] for CeB_6-NdB_6 the obtained results may be attributed to the effect of 5d-states spin polarization below T_{N1} and the formation of spin polarons of a small radius in AF state of GdB_6. On the other hand, the possible coherent displacement of Gd^{3+} ions inside the boron cage, proposed in [7], may also lead to the appearance of above mentioned anomalies. Additional measurements of transport and magnetic properties are required to elucidate the nature of both: the Hall effect enhancement below the T_{N1} and the emergence of anomalous Hall effect in AF(II) phase.

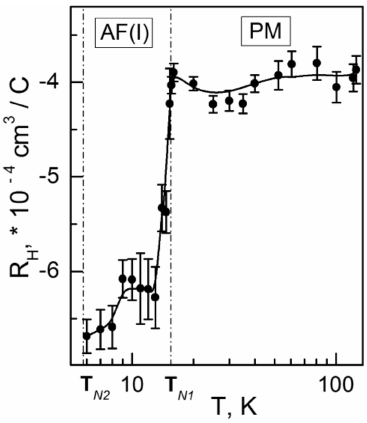

Fig. 2. The temperature dependence of Hall coefficient $R_H(T) = \rho_{H1}(T)/H$ in magnetic field $\mu_0 H = 1$ T (see the text).

4. Conclusions

The angular dependences of Hall resistivity of GdB_6 have been investigated. The appearance of the anomalous Hall effect in AF (II) phase was detected for the first time.

Acknowledgments

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