

The Research of Spin-Orbital Interaction in Intermetallic Compounds of System Gd-In on Paramagnetic Area

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Abstract: Normal, R_0 , and anomalous, R_S , components of the Hall coefficient are determined from the results of experimental investigations of temperature dependences of the Hall coefficient, magnetic susceptibility, and specific electrical resistance for intermetallic Gd_3In , Gd_3In_5 and $GdIn_3$ compounds. Effective parameters of spin-orbital interaction λ_{SO} of intermetallic compounds are calculated from anomalous components R_S of the Hall coefficient and specific electrical resistance. The results calculated for the band parameters and effective parameters of spin-orbital interaction λ_{SO} for Gd-In system intermetallides coincide by orders of magnitude with the results obtained from the optical spectra of pure REMs (rare-earth metals).

Key words: Hall coefficient, specific electrical resistance, magnetic susceptibility, effective spin-orbital interaction parameter.

1. Introduction

An integrated study of electric, magnetic, and galvanomagnetic properties of intermetallic compounds can be used to estimate the effective spin-orbital interaction parameter for the Gd-In system. According to our knowledge, there are no other works in this direction in Russia and abroad except Trudeau et al. [1] and Vedyayev et al. [2] who devoted to theoretical determination of the spin-orbital interaction parameter and results of investigations of the optical spectra.

Theoretical calculations of the spin-orbital interaction are rather complicated. It is well known (for example, see Ref. [3]) that the magnetic Hamiltonian of rare-earth ions is written as follows:

$$H = H_{coul. free} + H_{SO} + H_{cryst. field} + H_{earthmet} \quad (1)$$

From here the spin-orbital Hamiltonian has the form:

$$H_{SO} = \lambda \mathbf{L} \cdot \mathbf{S} \quad (2)$$

where λ is the effective spin-orbital interaction parameter. $\mathbf{L}$ —orbital angular momentum, $\mathbf{S}$ —spin angular momentum.

In this work, an attempt is undertaken for the first time to estimate the effective spin-orbital interaction parameter from experimental values of the specific electrical resistance, paramagnetic susceptibility, and the Hall coefficient. Exactly this fact provides originality of our approach in comparison with other authors, for example, Krupicka [4].

In the present work, electrical resistances ρ of the intermetallic Gd-In system were experimentally investigated in a wide temperature interval. At 77-1,000 K, they were measured using the conventional four-probe method, and at 800-2,000 K, they were measured by the contactless method of rotating magnetic field. This demonstrates that 4f-electrons, localized in sites of the Gd sublattice, play the dominant role in the formation of magnetic properties of the examined compounds.

Because of a number of circumstances indicated by Trudeau et al. [1], calculations of the effective spin-orbital interaction parameter are rather difficult.

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It is well known (for example, see Ref. [2]) that the anomalous Hall effect in REMs (rare-earth metals) is a consequence of the spin-orbital interaction. In the paramagnetic region, the Hall coefficient R_H can be written in the form:

$$R_H = \frac{\rho_H}{B} = R_0 + \frac{2e^2}{\mu_0 \mu_B \hbar g} \rho^2 \lambda_{SO} \chi = R_0 + R_S \chi \quad (3)$$

where $\mu_B = 0.927 \times 10^{-23}$ J/T is the Bohr magneton, $\mu_0 = 4\pi \times 10^{-7}$ G/m is the magnetic constant, $\hbar = 1.054 \times 10^{-34}$ J·s is the Planck constant, $e = 1.6 \times 10^{-19}$ C is the electron charge, g is the Landé factor, ρ is the specific resistance, and λ_{SO} is the effective spin-orbital interaction parameter. ρ_H —Hall resistivity, B —magnetic induction, R_0 —normal Hall coefficient, R_S —anomalous Hall coefficient, χ —magnetic susceptibility.

Then the effective spin-orbital interaction parameter λ_{SO} is:

$$\lambda_{SO} = \frac{R_S \mu_0 \mu_B \hbar g}{2e^2 \rho^2} \quad (4)$$

An analysis of the experimental data demonstrates a correlation between the Hall coefficient R_H and the magnetic susceptibility χ for the intermetallic Gd_3In , Gd_3In_5 and $GdIn_3$ compounds shown in Fig. 1. As can be seen from the figure, the dependence of R_H on χ is linear for the samples. Extrapolating R_H to zero (OY axis), the normal, R_0 , and anomalous, R_S , components of the Hall coefficients can be determined.

The effective spin-orbital interaction parameter λ_{SO} of electrons was calculated for the examined samples from the obtained anomalous component of the Hall coefficient R_S and the specific electrical resistance ρ .

The calculated results are given in Table 1.

As demonstrated by our calculations, the results on the band parameters and effective spin-orbital interaction parameters λ_{SO} for the intermetallic Gd-In systems coincide by the order of magnitude with the results obtained in Refs. [4-6] from the optical spectra of pure REM. The coincidence of χ and R_H signs demonstrates that the physical reason for the anomalous Hall effect is the spin-orbital interaction.

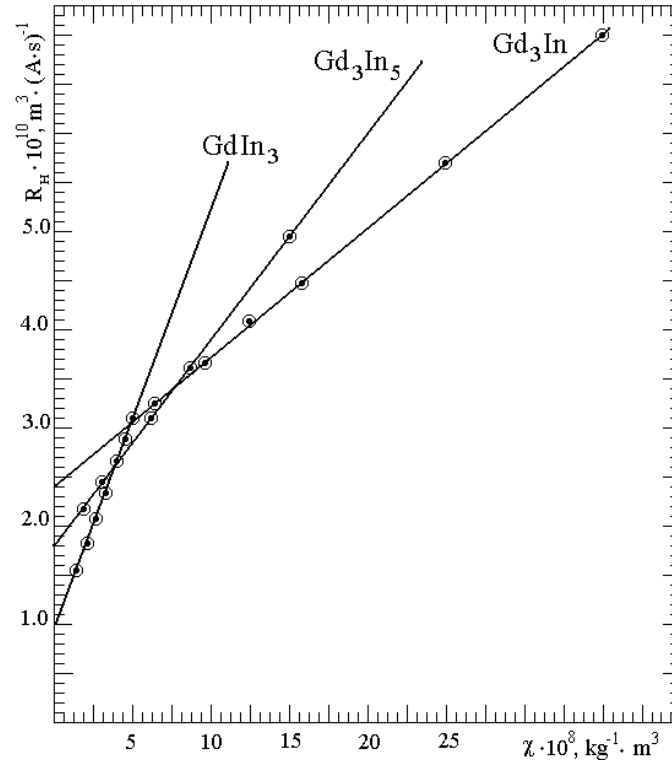


Fig. 1 Dependence of R_H on χ for the intermetallic Gd-In compounds.

Table 1 Normal and anomalous components of the Hall coefficient and effective spin-orbital interaction parameter.

Compounds	$R_0 \times 10^{10} \text{ (m}^3 \cdot \text{C}^{-1}\text{)}$	$R_S \times 10^7 \text{ (m}^3 \cdot \text{C}^{-1}\text{)}$	$\lambda_{\text{SO}} \cdot 10^{-13}, \text{ erg}$
Gd ₃ In	2.4	1.75	0.83
Gd ₃ In ₅	1.8	2.96	1.82
GdIn ₃	1.0	6.35	3.68

2. Conclusions

The normal, R_0 , and anomalous, R_S , components of the Hall coefficient were determined from experimental investigations of temperature dependences of the Hall coefficient, magnetic susceptibility, and specific electrical resistance of the intermetallic Gd₃In, Gd₃In₅ and GdIn₃ compounds.

However, the coefficient of the anomalous Hall effect decreases with increasing indium concentration, whereas the effective spin-orbital interaction parameter λ_{SO} increases. This can be explained for the Kondo model [7]. It is assumed that magnetic electrons are localized, their magnetizing action on the conduction electrons can be neglected, and that exactly non-magnetized conduction electrons are carriers of the anomalous Hall effect. Therefore, the Kondo model is applicable to REM, since 4*f*-electrons do not participate in the formation of current.

The effective spin-orbital interaction parameters

λ_{SO} of the examined intermetallic compounds were calculated from the anomalous components R_S of the Hall coefficient and the specific electrical resistance.

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