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A Study of Magnetic Properties of Rare-earth Monopnictides in High Magnetic Fields

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Chap. I Introduction

The purpose and the background of this thesis are explained in this chapter .

Rare earth monopnictides have much interest in the study of the magnetic properties in connection with their low carrier concentration. The exchange interaction between conduction electrons and localized 4f electrons has an important role in these interesting properties. An evaluation of the exchange on the basis of the experiments has been expected strongly by researchers. The ground state of the crystalline electric field (CEF) in PrSb and TmSb are singlet Γ_1. Although these materials have no spontaneous magnetic moment at zero magnetic field, the magnetization remarkably increases with external field because of the mixing the first excited state Γ_4 into the ground state Γ_1. The influences on the conduction electrons and the effect on the Fermi surface by the high magnetic field will be conspicuous owing to their low carrier concentration. High field de Haas-van Alphen (dHvA) and Shubnikov-de Haas (SdH) effect measurements have been performed to study the Fermi surface in the high magnetic field and to evaluate the exchange interaction. The acoustic de Haas (AdH) effect was measured to detect the angular dependence of the cross-sectional area of the Fermi surface and to study the electron-lattice interaction.

Chap. II Experimental

The methods of both the sample preparation and the experiments are described. Single crystals of PrSb and TmSb were grown by the Bridgman method using tungsten cruicbles. The AdH effect was measured in the wide temperature range from 0.5 K to 2.1 K. The dHvA and SdH effect measurements were performed using the hybrid magnets up to 300 kOe. The magnetization processes were measured up to 460 kOe using both hybrid and pulsed magnets. The internal field of magnetization and demagnetization were taken into account to analyze dHvA frequencies, because magnetic moment increases eminently at high field region.

Chap. III Magnetization process and Fermi surface of PrSb

The experimental results of magnetization, dHvA and SdH effect are presented. The magnetization processes which were measured up to 465 kOe are reproduced by the CEF model considering the exchange coupling. The field dependence of the dHvA frequency was found by a few percent in high field region. Spin-splittings of the Fermi surface were found to be smaller than the detective resolution for PrSb. This is because the larger energy difference between the first excited and ground state against the external field. The results of magnetization, dHvA and SdH effect measurements indicate that higher magnetic field than 500 kOe is necessary to observe the splitting.

Chap. IV Magnetization process and Fermi surface of TmSb

The experimental results of magnetization, dHvA, SdH and AdH effect are presented. Anisotropy of the saturation magnetization processes up to 300 kOe is explained by the CEF model considering the exchange coupling. The angular dependence of the cross-sectional area of the Fermi surface of TmSb was determined by AdH effect measurement for the first time. The main branches of AdH frequencies were found to be the same as LaSb. The effective masses were estimated to be 0.12-0.33 m_0. Both the spin-splitting and field dependence of the FFT spectra of dHvA oscillations were found in TmSb. The exchange interactions between the conduction electrons and the 4f electrons were evaluated: the interaction of α-branch, β-branch and γ-branch are 0.05, 0.09 and 0.05 eV, respectively.
The anisotropic behavior of the oscillatory intensity of the AdH effect is explained by the response theory. The electron-lattice interaction of the splitted α pocket are determined to $g_{xx}=g_{yy}=-0.7$, $g_{zz}=8.5$ and $g_{xx}=g_{yy}=1.0$, $g_{zz}=7.4$, respectively.

Chap. V Summary

The study is summarized and remaining problems are also posed.

Magnetization process of PrSb and TmSb is reproduced by the CEF model. The exchange coupling between the rare earth ions should be taken into account in the high magnetic region. The quadrupole interaction will play the important role in saturation field. The exchange interaction between the conduction electrons and localized electrons were estimated quantitatively from the spin-splittings.