

de Haas-van Alphen effect and magnetoresistance in CeRh_3B_2

Yoshihiko Inada*, Tomoyuki Ohkubo, Almgam Thamizhavel, Mineko Yamada, Shingo Kirita, Yoshichika Ōnuki

Graduate School of Science, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan

Abstract

CeRh_3B_2 has the highest Curie temperature of 120 K in the cerium compounds, with a saturation moment of about $0.4\mu_{\text{B}}/\text{Ce}$. We have succeeded in growing high-quality single crystals of CeRh_3B_2 , and measured the de Haas-van Alphen (dHvA) effect and the transverse magnetoresistance to clarify the 4f-electronic state. The dHvA frequencies are found to be in the range from 0.4–2 kT with the cyclotron mass of 1.7–2.4 m_0 . The magnetoresistance suggests the existence of open orbits on the Fermi surface.

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1. Introduction

CeRh_3B_2 has attracted a considerable interest due to its anomalous ferromagnetic property [1,2]. The Curie temperature $T_{\text{C}} \simeq 120$ K in CeRh_3B_2 is the highest value among the cerium compounds with non magnetic ligands. The usual magnetically ordering temperature is 1–10 K in the cerium compound, which is in contrast with 1–300 K in the uranium compound and 1–1000 K in the 3d-transition metal compound. Surprisingly the Curie temperature $T_{\text{C}} \simeq 120$ K is larger than $T_{\text{c}} = 90$ K in GdRh_3B_2 . This means that $T_{\text{C}} \simeq 120$ K in CeRh_3B_2 is by two orders of magnitude higher than $T_{\text{c}} \simeq 1$ K expected from the de Gennes factor. An ordered moment of $0.4\mu_{\text{B}}/\text{Ce}$, which is oriented within the basal plane, is relatively small compared to the usual value of about $1\mu_{\text{B}}/\text{Ce}$ [3].

From these high T_{C} -value and small moment it was suggested that ferromagnetism is not due to the 4f-localized moment but of the 4f-itinerant band in nature [4]. CeRh_3B_2 crystallizes in the hexagonal structure of space group P6/mmm with the lattice constants

($a = 5.48 \text{ \AA}$ and $c = 3.09 \text{ \AA}$). The Ce–Ce distance in the [0001] direction of 3.09 \AA is very short, and large 4f–4f direct mixing is expected in this direction [5]. Recently, the ferromagnetism in CeRh_3B_2 has been theoretically discussed from this viewpoint [6]. Previous NMR experiments, however, indicated that the magnetic moment of $0.4\mu_{\text{B}}/\text{Ce}$ is considerably localized at the cerium site below T_{C} and the spin fluctuation above T_{C} behaves as a localized moment system [7].

To explain the anomalous ferromagnetism in CeRh_3B_2 it is basically important to clarify the electronic state. The de Haas-van Alphen (dHvA) effect is the powerful method to detect the Fermi surface, although there has been no report on dHvA experiment of this compound. We have succeeded in growing high-quality single crystals of CeRh_3B_2 , and measured the dHvA effect and the transverse magnetoresistance.

2. Experimental and discussion

Single crystals of CeRh_3B_2 were grown by the Czochralski pulling method in a tetra-arc furnace. Starting materials were 99.9%-pure (3N) Ce, 4N-Rh and 3N-B. An ingot was purified by the electro-transport method in high vacuum of 10^{-10} Torr at 900°C .

*Corresponding author. Physics II Laboratory, Department of Science Education, Faculty of Education, Okayama University 700-8530 Japan.

E-mail address: y-inada@cc.okayama-u.ac.jp (Y. Inada).

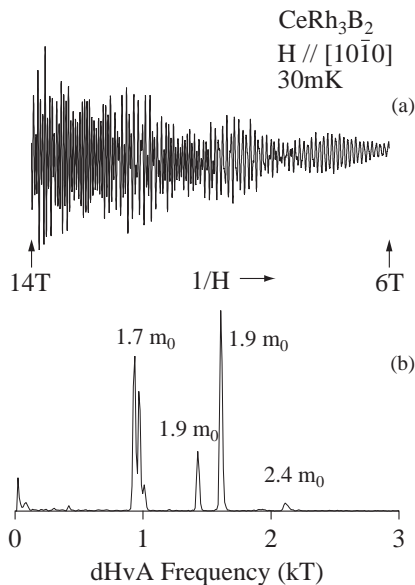


Fig. 1. (a) Typical dHvA oscillation and (b) the corresponding FFT spectrum in CeRh_3B_2 . The values of cyclotron masses are indicated for each branch.

The electrical resistivity at 1.4 K and the resistivity ratio $\rho_{\text{RT}}/\rho_{1.4\text{K}}$ were $2.8\ \mu\Omega\ \text{cm}$ and 60 for the current along $[10\bar{1}0]$. This large value of the resistivity ratio indicates that the single crystal is of high-quality. The de Haas-van Alphen experiments were performed at high magnetic fields up to 17 T and low temperatures down to 30 mK by the standard field-modulation method.

Fig. 1 shows a typical dHvA oscillation and its fast Fourier transform (FFT) spectrum for $H\parallel[10\bar{1}0]$. The dHvA frequency F is proportional to the extremal (maximum or minimum) cross-sectional area S_F of the Fermi surface. Four dHvA branches are observed: 0.93 (0.97), 1.43, 1.61 and 2.11 kT. From the angular dependence of the dHvA frequencies, it is suggested that the former three branches correspond to closed Fermi surfaces. The last branch with $F = 2.11$ kT is not observed around the $[0001]$ direction, suggesting a multiply-connected Fermi surface. The effective mass of $1.7\text{--}2.4\ m_0$ is relatively light compared to the electronic specific heat $\gamma \simeq 15\ \text{mJ}/\text{K}^2\ \text{mol}$. We believe that another Fermi surfaces with a much larger dHvA frequency and cyclotron mass should exist in CeRh_3B_2 .

Fig. 2 shows the angular dependence of the magnetoresistance $\Delta\rho/\rho = \{\rho(H) - \rho(0)\}/\rho(0)$ under a constant field $H = 12\ \text{T}$ for the current J along $[0001]$ and $[11\bar{2}0]$. The transverse magnetoresistance gives the information of the Fermi surface, whether electron and hole carriers are compensated or uncompensated, and whether the Fermi surface possesses open orbit or not.

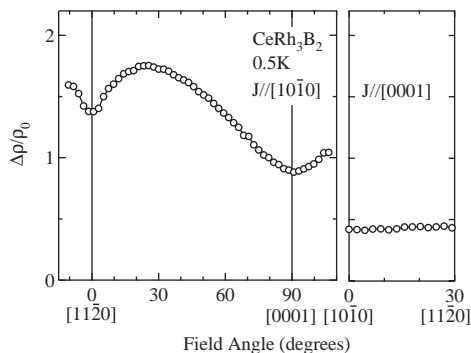


Fig. 2. Angular dependence of the magnetoresistance for CeRh_3B_2 .

From the number of the valence electrons, the non-4f reference compound LaRh_3B_2 is a compensated metal with equal carrier numbers of electron and holes.

In the configuration of $J\parallel[0001]$, the transverse magnetoresistance saturates in the whole angle region. On the other hand, for $J\parallel[10\bar{1}0]$, the magnetoresistance saturates around $H\parallel[0001]$, but increases as H^n ($n > 1$) around $H\parallel[11\bar{2}0]$. These results indicate this compound to be a compensated metal with open orbits within the basal plane, if we assume the 4f-electrons are localized. If the 4f-electrons are itinerant, resulting in an uncompensated metal, open orbits run along the current direction parallel to $[10\bar{1}0]$. At present it is not clear whether this compound is the compensated metal or the uncompensated metal, however, the MR results surely indicate the existence of multiply-connected Fermi surface leading to open orbits.

In conclusion, we have succeeded in observing the dHvA signal in CeRh_3B_2 , indicating three closed Fermi surfaces and one multiply-connect Fermi surface with the cyclotron mass of $1.7\text{--}2.4\ m_0$. The result of the magnetoresistance suggests the existence of open orbits.

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