De Haas-van Alphen effect of $CeRhIn_5$ under pressure

Hiroaki Shishido [a,1], Rikio Settai [a], Shingo Araki [a,2], Taiki Ueda [a], Yoshihiko Inada [a], Hisatomo Harima [b], Yoshichika Ōnuki [a]

[a] *Graduate School of Science, Osaka University, Toyonaka, Osaka, 560-0043, Japan*

[b] *The Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka 567-0047, Japan*

Abstract

We have studied the de Haas-van Alphen (dHvA) effect under pressure for an antiferromagnet $CeRhIn_5$, where the antiferromagnetic state is changed into the superconducting state at higher pressures than 1.6 GPa. It is clarified from the present dHvA experiment that the topology of the Fermi surface is unchanged up to 2.1 GPa but the cyclotron mass increases strongly above 1.6 GPa. Superconductivity is found to be realized in this heavy fermion state.

Key words: pressure-induced super conductivity, dHvA effect, $CeRhIn_5$

1. Introduction

Pressure-induced superconductivity is one of the most interesting assures in the strongly correlated electron systems. $CeRhIn_5$ is such a superconductor [1]. It crystallizes in the tetragonal structure with alternating layers of $CeIn_3$ and $RhIn_2$, stacked sequently along the [001] direction (c-axis). When pressure p is applied to $CeRhIn_5$, the Néel temperature T_N=3.8 K increases slightly with increasing pressure but decreases above 1 GPa. Superconductivity appears above 1.6 GPa, and the superconducting transition temperature T_c has a maximum of T_c=2 K around 2.5 GPa [2].

The purpose of the present study is to report the electronic state when pressure reaches the superconducting state of $CeRhIn_5$ via a microscopic probe of the de Haas-van Alphen (dHvA) experiment. The dHvA results of $CeRhIn_5$ are compared to the previous results of a non-4f reference compound $LaRhIn_5$ and an itinerant 4f-electron system of $CeCoIn_5$ [3,4].

[1] Corresponding author. E-mail: shishido@crystal.phys.sci.osaka-u.ac.jp

[2] Present address: Advanced Science Research Center, Japan Atomic Energy Research Institute, Tokai,Ibaraki 319-1195, Japan

2. Experimental Results and Discussion

Fig. 1 shows the dHvA oscillation and the corresponding fast Fourier transformation (FFT) spectrum for $CeRhIn_5$ at 1.28GPa. The dHvA frequency F ($=\hbar c S_F/2\pi e$) is proportional to the extremal (maximum or minimum) cross-sectional area of the Fermi surface S_F. Branches named β_2, α_1 and $\alpha_{2,3}$ correspond to main cylindrical Fermi surfaces in $CeRhIn_5$ [4]. These dHvA branches are well identified by the theoretical Fermi surfaces of the non-4f reference compound $LaRhIn_5$. A dHvA frequency F=6.13$\times 10^7$ Oe of branch β_2 in $CeRhIn_5$ is the same as 6.13$\times 10^7$ Oe in $LaRhIn_5$, but is smaller than 7.35$\times 10^7$ Oe in $CeCoIn_5$. The dHvA frequencies of branches α_1 and $\alpha_{2,3}$ in $CeRhIn_5$ are also the same as those of $LaRhIn_5$, but are smaller than those of $CeCoIn_5$ with an itinerant 4f-electron character [3,4]. From these experimental results, it was concluded that the contribution of the 4f electrons to the volume of the Fermi surface in $CeRhIn_5$ is negligibly small, indicating that the 4f electrons in $CeRhIn_5$ are localized.

Fig. 2 shows the pressure dependence of the dHvA frequency for main branches β_2, α_1 and $\alpha_{2,3}$ in $CeRhIn_5$. The dHvA frequency is almost unchanged

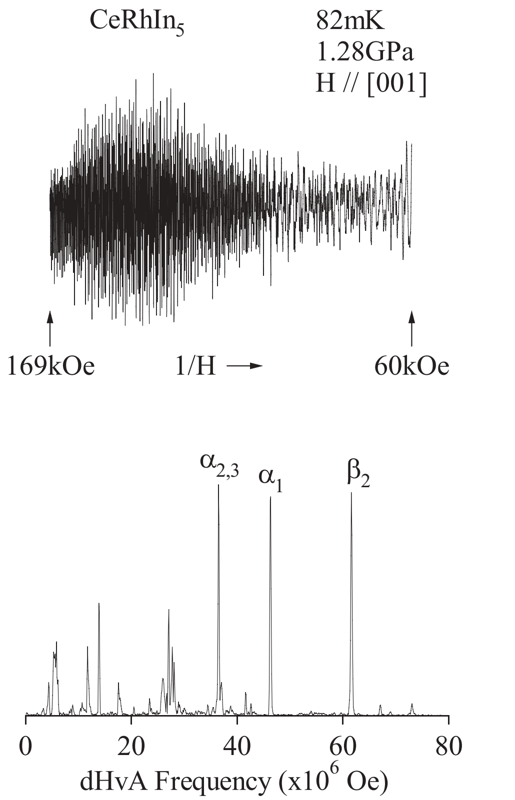

Fig. 1. dHvA oscillation and its FFT spectrum in $CeRhIn_5$.

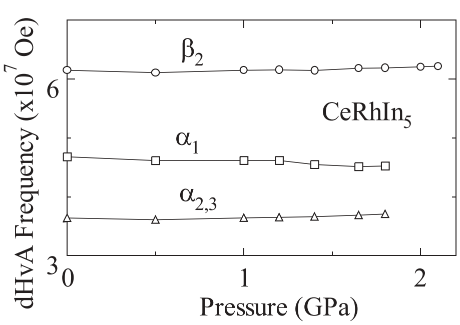

Fig. 2. Pressure dependence of the dHvA frequency in $CeRhIn_5$.

against the pressure up to 2.1 GPa. It means that the topology of the main Fermi surfaces is almost unchanged.

On the other hand, the cyclotron mass m_c^* increases strongly with increasing pressure, as shown in Fig. 3, where the cyclotron mass of branch β_2 (m_c^*=5.7 m_0) at ambient pressure reaches about 40 m_0 at 2 GPa. Here

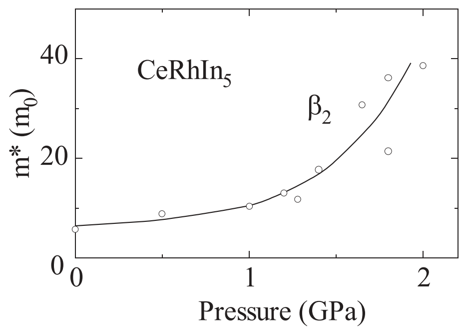

Fig. 3. Pressure dependence of the cyclotron mass of branch β_2 in $CeRhIn_5$.

we note that the cyclotron mass was determined by the temperature dependence of the dHvA amplitude.

In the cerium compound, the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction and the many-body Kondo effect compete with each other [5]. The degree of mass enhancement depends on the degree of competition between the RKKY interaction and the Kondo effect, which in turn depends on the degree of hybridization of the $4f$ electrons with the conduction electrons. The heavy fermion state with an extremely large cyclotron mass is formed around the pressure of 2 GPa. It is thus concluded that pressure-induced superconductivity in $CeRhIn_5$ is realized in this heavy fermion state.

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