DE HAAS–VAN ALPHEN EXPERIMENTS UNDER PRESSURE IN UGe_2*

R. Settai[a], M. Nakashima[a], H. Shishido[a], Y. Haga[b], H. Yamagami[c] and Y. Ōnuki[a,b]

[a]Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan
[b]Advanced Science Research Center, Japan Atomic Energy Research Institute
Tokai, Ibaraki 319-1195, Japan
[c]Faculty of Science, Department of Physics, Kyoto Sangyo University
Kita-ku, Kyoto 603-8555, Japan

(Received July 10, 2002)

We have studied the electronic state in UGe_2 via the de Haas–van Alphen effect under pressure. The cyclotron masses are determined in the strongly polarized phase and in the paramagnetic phase for magnetic field along the c-axis and the results are compared with those along a- and b-axes.

PACS numbers: 71.18.+y, 71.27.+a

1. Introduction

Recently quantum critical phenomena induced by pressure have been investigated intensively in cerium and uranium compounds. The coexistence of superconductivity with magnetism is one of the important issues in the quantum critical phenomena. A ferromagnetic compound UGe_2 with the Curie temperature $T_C = 52$ K shows the pressure-induced superconductivity in the pressure range from 1.0 to 1.6 GPa [1, 2]. Surprisingly, the superconducting phase is observed even though the sample is ferromagnetic with reduced Curie temperature.

We have studied the electronic state in UGe_2 via the de Haas–van Alphen (dHvA) effect under pressure [3, 4]. The main Fermi surface in UGe_2 is a parallelepiped, elongated along the b-axis of the orthorhombic crystal structure. The dHvA oscillation of the main Fermi surface is clearly observed for $P < 1.2$ GPa (strongly polarized phase) as well as for $P > 1.5$ GPa

* Presented at the International Conference on Strongly Correlated Electron Systems, (SCES 02), Cracow, Poland, July 10–13, 2002.

(paramagnetic phase) for magnetic field along b-axis. However, the dHvA oscillation either disappears or is strongly reduced in the pressure region $1.2 < P < 1.5$ GPa, which corresponds to the weakly polarized phase.

The origin of the disappearance or the strong reduction of the oscillation is closely related to the enhancement of the cyclotron effective mass and/or the reduction of the mean free path of the heavy electrons. The cyclotron masses in the paramagnetic state ($P > 1.5$ GPa) are about three times larger than those in the strongly polarized state ($P < 1.2$ GPa). On the other hand, the mean free paths are almost the same for both states. Therefore, the cyclotron effective mass in the weakly polarized state should be larger than that in the strongly polarized and paramagnetic states and/or the mean free path in the weakly polarized state should be smaller than that in the strongly polarized and paramagnetic states. This could be a reason why the dHvA oscillation is not observed in the weakly polarized state, $1.2 < P < 1.5$ GPa. Terashima *et al.* also reported the dHvA oscillations of UGe_2 [5]. They observed the dHvA oscillation not only in the pressure region $P < 1.2$ GPa and $P > 1.5$ GPa but also in $1.2 < P < 1.5$ GPa for the field along b-axis, although the oscillating amplitude in $1.2 < P < 1.5$ GPa is extremely small.

In order to understand and clarify the previous dHvA results, we have carried out dHvA experiments on a high quality single crystal (RRR=500) for magnetic field along c-axis. Relatively small Fermi surfaces with small cyclotron masses are observed along the c-axis compared to the b-axis [6]. Therefore one can expect the dHvA oscillation in the pressure region of $1.2 < P < 1.5$ GPa.

The dHvA experiment under pressure was done by the standard field modulation method with a modulation field of 100 Oe and a modulation frequency of 3.5 Hz in magnetic fields up to 170 kOe and at low temperatures down to 90 mK, using a MP35N piston-cylinder pressure cell.

2. Experimental result

Figure 1 shows (a) dHvA oscillations and (b) corresponding fast Fourier transformation (FFT) spectra at several pressures. At ambient pressure we observed five fundamental dHvA frequencies as indicated by arrows in the figure. These branches are in agreement with those of the previous study [6]. According to the previous work [6], the branch with the dHvA frequency of 2.34×10^6 Oe is an ellipsoidal small pocket Fermi surface. This branch possesses a relatively small cyclotron effective mass $m_c^*=5.2\,m_0$, as listed in Table I. At 1.0 GPa this branch increases in volume, which suggests that the branch comes from the minority spin band. Some branches disappear most likely due to an increase of the cyclotron mass. The dHvA oscillation disappears completely at 1.3 GPa, and recovers clearly at 1.63 GPa

($P > P_c$). This behavior is very similar to the dHvA results along the b-axis. The cyclotron mass $7.0\,m_0$ for the dHvA frequency 4.27×10^6 Oe at 1.63 GPa is almost same as $7.4m_0$ for the dHvA frequency 2.82×10^6 Oe at 1.0 GPa. The corresponding branch at 1.3 GPa, if it exists, might possess a large cyclotron mass of 15–$20\,m_0$.

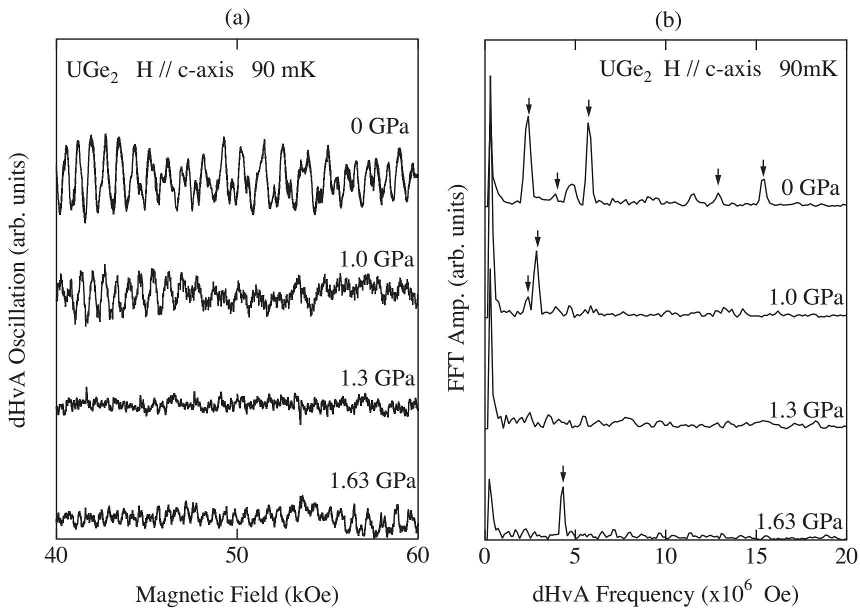

Fig. 1. (a) dHvA oscillations and (b) corresponding FFT spectra at several pressures for the field along the c-axis in UGe_2.

TABLE I

de Haas–van Alphen frequency F and the cyclotron effective mass m_c^* for the magnetic field along the c-axis under pressure in UGe_2.

$P = 0$ GPa		$P = 1.0$ GPa		$P = 1.63$ GPa	
$F(\times10^6$ Oe)	$m_c^*(m_0)$	$F(\times10^6$ Oe)	$m_c^*(m_0)$	$F(\times10^6$ Oe)	$m_c^*(m_0)$
2.34	5.2	2.35	2.7	4.28	7.0
		2.82	7.4		
3.86	3.4				
5.75	12				
12.9					
15.4	22				

3. Discussion

We performed the dHvA experiment under pressure in UGe_2 for the magnetic field along the c-axis. The dHvA oscillation was observed in the strongly polarized state (0 and 1.0 GPa) and paramagnetic state (1.63 GPa), while the oscillation was not observed in the weakly polarized state(1.3 GPa). The reason why the dHvA oscillation disappears in the weakly polarized state for the field along the b- and c-axes might be that there is an enhancement of the cyclotron effective mass and a reduction of the mean free path. On the other hand, the dHvA oscillation was observed in the weakly polarized state for the field along the a-axis [4]. The H–P phase diagram indicates the formation of the paramagnetic phase, the weakly polarized phase and the strongly polarized phase. The phase boundaries which demarcate the strongly polarized phase from the weakly polarized phase (H^*) and the weakly polarized phase from the paramagnetic phase ($H_{\rm c}$) increase with the increase of pressure under magnetic field directed along the the a-axis. Therefore, the dHvA oscillations both in the weakly and strongly polarized phases are observed under constant pressure. The cyclotron mass in the weakly polarized phase is twice as large as that of the strongly polarized phase for similar dHvA frequencies. The mean free path is, however, almost the same for both phases. The smaller value of the mean free path of the heavy electron for field along the b- and c-axes as compared to that along the a-axis is attributed to the alignment of the magnetic moment along the a-axis.

This work was financially supported by the Grant-in-Aid for COE Research (10CE2004) from the Ministry of Education, Culture, Sports, Science and Technology of Japan. We are grateful to Professor S. Ramakrishnan for critical reading of the manuscript.

REFERENCES

[1] S.S. Saxena *et al.*, *Nature* **604**, 587 (2000).
[2] A. Huxley *et al.*, *Phys. Rev.* **B63**, 144519 (2001).
[3] R. Settai *et al.*, *J. Phys.: Condens. Matter* **14**, L29 (2002).
[4] Y. Haga *et al.*, *J. Phys.: Condens. Matter* **14**, L125 (2002).
[5] T. Terashima *et al.*, *Phys. Rev. Lett.* **87**, 166401 (2001).
[6] K. Satoh *et al.*, *J. Phys. Soc. Jpn.* **61**, 1827 (1992).