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2003 J. Phys.: Condens. Matter 15 S2011

(http://iopscience.iop.org/0953-8984/15/28/316)

INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS: CONDENSED MATTER

J. Phys.: Condens. Matter **15** (2003) S2011–S2014 PII: S0953-8984(03)62620-2

The de Haas–van Alphen effect in URu_2Si_2 under pressure

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Received 12 November 2002
Published 4 July 2003
Online at stacks.iop.org/JPhysCM/15/S2011

Abstract

We carried out a de Haas–van Alphen (dHvA) experiment under pressure on a heavy-fermion superconductor, URu_2Si_2. The dHvA frequency, which corresponds to a nearly spherical Fermi surface, increases slightly with increasing pressure, while the corresponding cyclotron mass decreases considerably. Neither the dHvA frequency nor the cyclotron mass exhibit any abrupt change at the critical pressure of 1.5 GPa. The present result is thus inconsistent with a recent phase-separation proposal.

1. Introduction

URu_2Si_2 is a very interesting heavy-fermion compound, exhibiting two successive transitions at $T_c = 1.4$ and $T_0 = 17.5$ K. Neutron diffraction study indicated the development of a simple type-I antiferromagnetic order with a tiny 5f magnetic moment of 0.03 μ_B along the tetragonal [001] direction below T_0 [1]. Recent neutron scattering and NMR experiments under pressure shed new light on this phase transition. It was clarified from a neutron scattering experiment that the magnetic moment increases linearly as a function of pressure, saturates in the pressure region from 1.0 to 1.5 GPa, with a moment of 0.25 μ_B, and jumps to 0.4 μ_B, indicating a sharp phase transition at $P_c = 1.5$ GPa [2]. Furthermore, the result of an NMR experiment indicated that there exist distinct antiferromagnetic and paramagnetic regions, and with increasing pressure the antiferromagnetic region increases in size, reaching 100% of the antiferromagnetic volume fraction at 1.0 GPa [3].

The de Haas–van Alphen (dHvA) effect technique is the most powerful method for determining the topology of the Fermi surface, the cyclotron effective mass and the Dingle temperature. Previously we studied the dHvA effect and clarified the Fermi surface properties of URu_2Si_2 [4]. If the recent NMR experiment is to be relied upon, the dHvA branch detected at ambient pressure is mainly due to the paramagnetic region. The recent experiment proposes that the volume fractions of the paramagnetic and antiferromagnetic regions are about 99 and

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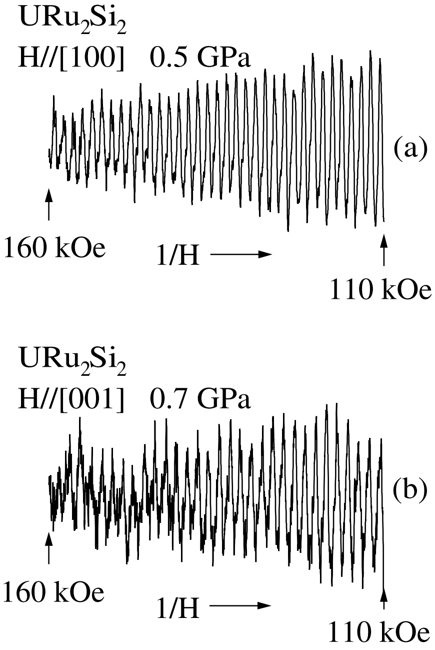

Figure 1. The dHvA oscillation in (a) the field along [100] at 0.5 GPa and (b) that along [001] at 0.7 GPa.

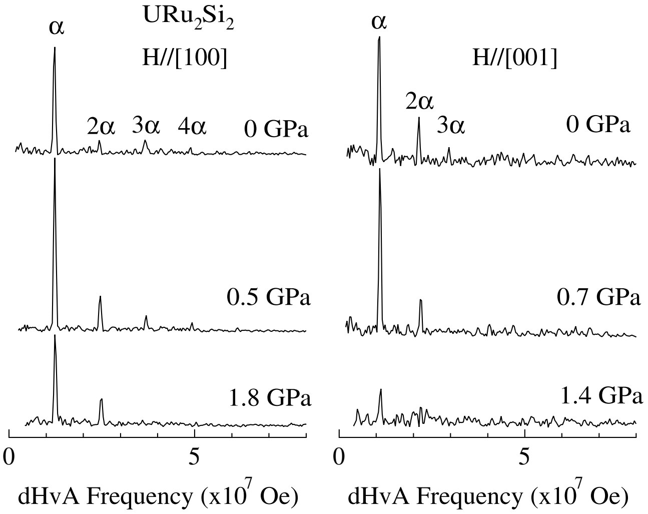

Figure 2. The FFT spectra of the dHvA oscillation in (a) the field along [100] at 0, 0.5, 1.8 GPa and (b) that along [001] at 0, 0.7, 1.4 GPa.

1%, respectively, as judged from the tiny moment of 0.03 μ_B. The topology of the Fermi surface is generally influenced by the antiferromagnetic ordering. At about 0.5 GPa we expect dHvA branches of two kinds based on the paramagnetic and antiferromagnetic regions. To clarify this, we carried out a dHvA experiment under pressure.

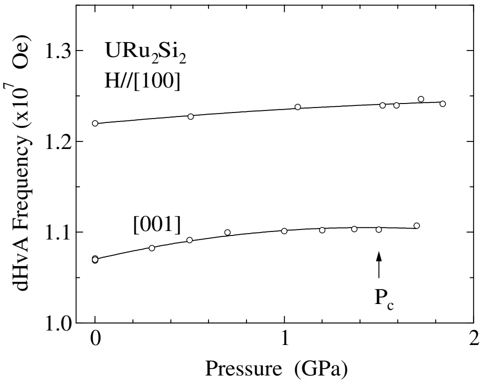

Figure 3. Pressure dependences of the dHvA frequency for branch α in URu_2Si_2.

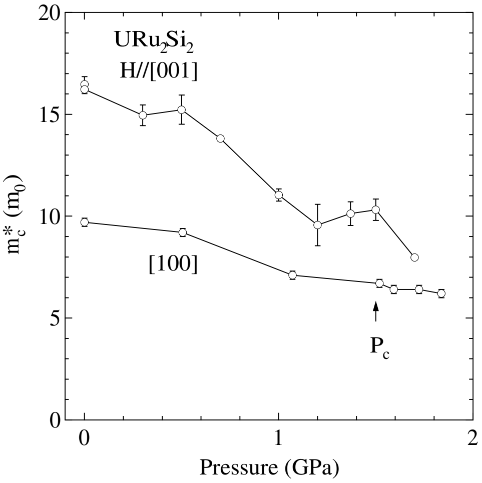

Figure 4. Pressure dependences of the cyclotron mass for branch α in URu_2Si_2.

2. Experimental results and analyses

Figures 1 and 2 show the dHvA oscillation in the field along [100] at 0.5 GPa (a) and that along [001] at 0.7 GPa (b) under pressure, and the corresponding fast Fourier transform (FFT) spectra, together with FFT spectra at different pressures. The dHvA branches detected are a branch named α and its higher harmonics, where the branch α is observed at ambient pressure and is known to be nearly spherical in shape. The fundamental branch is thus the only one and it is unchanged by pressure. As shown in figure 3, the dHvA frequency, for both field directions, increases monotonically with increasing pressure and indicates no abrupt change at $P_c = 1.5$ GPa.

Figure 4 shows the pressure dependence of the cyclotron mass m_c^*. The cyclotron mass decreases considerably with increasing pressure. In the heavy-fermion system, the magnetic specific heat of the 5f electrons is partially changed into an electronic specific heat. The present result is consistent with the pressure dependence of the magnetic moment. That is, the larger the magnetic moment, the smaller the electronic specific heat coefficient or the cyclotron mass. It is, however, noted that an abrupt change of the cyclotron mass at P_c is not observed within experimental error and that there is no abrupt change of the dHvA frequency as mentioned above.

We also determined the Dingle temperature and estimated the mean free path for branch α for the field along [100]. The mean free path is 1100 Å (±50 Å), approximately independently of the pressure.

It is concluded from the present dHvA experiment that the dHvA frequency is almost unchanged by pressure, showing only a slight increase, and that the cyclotron mass changes considerably under pressure, reflecting a change of the magnetic moment. The present dHvA experiment under pressure is thus inconsistent with the phase-separation proposal based on an NMR experiment, although there is a possibility that the Fermi surfaces are approximately the same for paramagnetic and antiferromagnetic regions.

Acknowledgments

This work was financially supported by a Grant-in-Aid for COE Research (10CE2004) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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