Effect of Pressure on the Magnetoresistance of the CeRh_2Si_2

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The magnetoresistance (MR) of single crystalline CeRh_2Si_2 has been measured at high pressure up to 2.3 GPa and at 4.2 K. At ambient pressure, the large MR has been observed. It is found that in a magnetic field dependence of MR, it shows a crossover near the critical pressure $P_{C2} = 0.6$ GPa, from H to a H^2 dependence. The magnitude of MR, $\Delta R(P, H=9 \text{ T})/R(P)$, shows a sudden decrease near P_{C2} , where the magnetic structure changes. These results are discussed on the basis of pressure induced quantum phase transition.

Key words: electrical resistivity, magnetoresistance, antiferromagnet, Kondo effect, quantum phase transition

1. Introduction

CeT_2Si_2 (T : transition metal) crystallizes in a ThCr_2Si_2 -type tetragonal structure. These compounds have been well-known to show many interesting electronic properties such as magnetic ordering, superconductivity, and so forth. These anomalous properties are considered to be due to electronic and magnetic instability since several kinds of interactions such as RKKY interaction, the Kondo effect and crystalline electric field are competing each other in these compounds¹⁾.

CeRh_2Si_2 is an antiferromagnet at ambient pressure. Neutron diffraction study suggested the Bragg reflection which represents the magnetic modulation with the wave vector of $q_1 = (0.5, 0.5, 0)$ below $T_{N1} = 36$ K, where the magnetic moment are arranged along the c -axis. Furthermore, the second Bragg reflection due to the wave vector of $q_2 = (0.5, 0.5, 0.5)$ starts growing at $T_{N2} = 24$ K²⁾.

It has been reported that the resistivity and the thermal expansion shows anomalies near T_{N1} and T_{N2} ^{3,4)}. Both of transitions, T_{N1} and T_{N2} are suppressed by applying pressure and disappear near the critical pressure at $P_{C1} \sim 1.0$ GPa and $P_{C2} \sim 0.6$ GPa respectively^{2,4)}. It means that there will be two phase transitions at zero-temperature, that is, quantum phase transitions, one of which, P_{C1} , separates magnetic ordering phase with the wave vector of q_1 from one with no long range order, and another, P_{C2} , does two magnetic phases.

It is expected that some anomalous behavior occurs at low temperature near critical points. Indeed, the superconductivity appears at 400 mK above 0.9 GPa, near

the critical pressure required to suppress antiferromagnetic ordering⁵⁾.

It suggests that the quench of the magnetic ordering affects the electronic structure near the Fermi surface under the critical pressures at P_{C1} and P_{C2} . It is well known that information of magnetoresistance is useful to know the topology of the Fermi surface.

In the present work, we report the magnetoresistance of a single crystalline under pressure in detail and discuss the electronic properties near the quantum critical point induced by pressure.

2. Experimental

Single crystal of CeRh_2Si_2 was grown by Czochralski pulling method in a tetra-ark furnace. The sample was annealed in a quartz tube under vacuum of $\sim 10^{-6}$ torr at 900 °C for one week. The electrical resistance was measured by the usual of four-probe DC method for the current along the a -axis. The residual resistivity ratio is 32 at ambient pressure. High pressure up to 2.3 GPa was generated by using a piston cylinder type apparatus in which a mixture of Fluorinerts of FC70 and FC77 in ratio 1:1 was used as a pressure transmitting medium. The magnetic field of 9 T at 4.2 K was applied along the c -axis by Oxford superconducting magnet. Details of the pressure apparatus have been reported previously⁶⁾.

3. Results

3.1. Electrical resistivity at high pressure

Fig. 1 shows the electrical resistivity at high pressure as a function of temperature when the current direction is along the a -axis. At ambient pressure, the resistivity shows a sudden decrease near 35 K ($\sim T_{N1}$). Moreover, the resistivity shows a small anomaly at 24 K ($\sim T_{N2}$). The anomalies at T_{N1} and T_{N2} correspond to the magnetic phase transitions, which were mentioned in section 1. The pressure dependence of T_{N1} and T_{N2} is plotted in Fig. 2(a). It is found that T_{N1} disappears around 1.0 GPa ($\sim P_{C1}$) and T_{N2} around 0.6 GPa ($\sim P_{C2}$), which are good agreement with those reported previously^{2,3)}.

The resistivity is described as $\rho(T) = \rho_0 + AT^2$ at low temperature, where ρ_0 is the residual resistivity and A is

Fig. 1 Temperature dependence of the electrical resistivity of CeRh_2Si_2 when the current is along the a -axis.

the coefficient. The values of ρ_0 and A for a -axis are plotted in Fig. 2(b) as a function of pressure $A(P)$ shows a peak around the critical pressure $\sim P_{C1}$, indicating large spin fluctuation which corresponds to the pressure-induced quantum phase transition. The peak in $A(P)$ suggests a occurrence of superconductivity in this system⁵⁾. It is consistent with the result of pressure dependence of Sommerfeld coefficient γ of specific heat⁷⁾. However, no anomaly is observed in $A(P)$ near P_{C2} . Since it is reported that this transition is of first order⁸⁾, it is interpreted that no fluctuation exist and then the coefficient $A(P)$ is not affected.

Fig. 2 Pressure dependence of (a) the critical temperatures T_{N1} and T_{N2} , and (b) the residual resistivity and the coefficient of T^2 of CeRh_2Si_2 .

The residual resistivity, $\rho_0(P)$, on the other hand, shows an anomaly near P_{C2} . It increases slightly as pressure increases, and decreases with a minimum near 0.6 GPa ($\sim P_{C2}$). The result indicates that the critical pressure P_{C2} affects the magnitude of ρ_0 , i.e., the first order phase transition at P_{C2} is accompanied by a large change in the value of ρ_0 .

3.2. Magnetoresistance (MR) at high pressure

Fig. 3 shows the MR-ratio $\Delta R(P, H)/R(P)$ of CeRh_2Si_2 when the current is applied along the a -axis and the magnetic field along the c -axis at 4.2 K. Below 0.31 GPa, $\Delta R(P, H)/R(P)$ increases linearly as the magnetic field increases. Above 0.58 GPa, on the other hand, it shows a H^2 dependence like normal metal. It suggests that a change in electronic state occurs near 0.6 GPa $\sim P_{C2}$. No saturation in the MR-ratio is observed up to 9 T at all pressures, implying an appearance of the open orbits. For clarifying the Fermi surface in more detail, it is needed to measure the high field magnetoresistance or the angular dependence of it.

Fig. 3 MR-ratio of CeRh_2Si_2 at 4.2 K when the current is along the a -axis and the magnetic field along the c -axis.

The pressure dependence of the resistivity in several magnetic fields is plotted in Fig. 4. It is found that $\rho(P)$ shows two anomalies, one of which is a sudden decrease around 0.6 GPa ($\sim P_{C2}$) and the other is a maximum around 1.0 GPa ($\sim P_{C1}$). It is interpreted that the maximum near P_{C1} comes from large spin fluctuation which is enhanced near the pressure-induced quantum critical point. The resistivity exhibits a T^2 dependence at low temperature. The coefficient $A(P)$ is related to the

magnitude of spin fluctuation and shows a maximum near P_{C1} , as indicated in Fig. 2. Because of that, large value of AT^2 term contributes to $\rho(P)$ at 4.2 K and then $\rho(P)$ also shows a maximum as seen in Fig. 4. even when it shows no anomaly at $T = 0$ K.

On the other hand, the anomaly near P_{C2} is not related to any critical fluctuation since this transition is of first order⁵⁾. It is suggested that the magnetic phase transition near P_{C2} occurs by a change of spin structure²⁾.

Fig. 4 Pressure dependence of the resistivity at 4.2 K in the magnetic field at $H = 0$ T and 9 T.

4. Discussion

Some of heavy fermion compounds exhibit a large magnetoresistance with a H^n dependence where $2 > n > 1$ corresponding to the electronic state near the fermi surface. To describe the crossover in MR-ratio of CeRh_2Si_2 from H to a H^2 dependence with increasing pressure, the MR-ratio at 4.2 K is fitted by the formula $\Delta R(H, P)/R(P) = \alpha H^n$. To determine the values of n and α , the MR-ratio is plotted in logarithmic scale in Fig. 5. It shows that n increases with increasing pressure while the coefficient α decreases.

Fig. 5 MR-ratio fitted by the formula $\Delta R(H, P)/R(P) = \alpha H^n$ at 4.2 K.

The values of n and α are shown in Fig. 6 as a function of pressure. It is found that the power n shows a sudden increase from 1.1 to 1.7 near $P_{C2} \sim 0.6$ GPa. This result indicates that some kind of crossover in the electronic state or quantum phase transition occurs at the critical pressure P_{C2} .

Fig. 6 Plot of the values of n and α as a function of pressure at 4.2 K.

5. Conclusion

We have observed the electrical resistivity and magnetoresistance of single crystalline CeRh_2Si_2 under high pressure. It is found that two magnetic phase transition temperatures T_{N1} and T_{N2} disappear at high pressure and the MR-ratio shows a crossover near the critical pressure $P_{C2} = 0.6$ GPa, from H to H^2 dependence. The results are related to pressure induced quantum phase transition.

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