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High-pressure effect on the electrical resistivity in $CeNiGe_3$ and $CeNi_2Al_5$

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Abstract

We have measured the electrical resistivity of antiferromagnetic Kondo compounds $CeNiGe_3$ and $CeNi_2Al_5$ under pressure. In $CeNiGe_3$, Néel temperature T_N initially increases with increasing pressure P up to 3 GPa, then decreases rather steeply with further increasing pressure, and becomes zero at a critical pressure $P_c \simeq 5.5$ GPa. The A and ρ_0 values of the resistivity $\rho = \rho_0 + AT^2$ in the Fermi liquid relation become maximum around P_c. Superconductivity is found below 0.48 K in a wide pressure region from 4 to 10 GPa. In $CeNi_2Al_5$, the similar pressure dependence of T_N is found, has a maximum at 3.9 GPa, and becomes zero around 6 GPa.

Keywords: High pressure; Superconductivity; $CeNiGe_3$; $CeNi_2Al_5$

The electronic states in cerium compounds, where the RKKY interaction and the Kondo effect compete with each other, can be tuned by pressure. Namely, the application of pressure controls the magnetic interaction and hybridization between the f electrons and conduction electrons. The crossover from the magnetically ordered state to the non-magnetic state under pressure, crossing the quantum critical point, is currently the most interesting issue in cerium compounds.

We studied two antiferromagnetic Kondo compounds with the orthorhombic structure,

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$CeNiGe_3$ with Néel temperature $T_N = 5.5\,K$ [1] and $CeNi_2Al_5$ with $T_N = 2.6\,K$ [2] by measuring the electrical resistivity under pressure.

The polycrystal sample of $CeNiGe_3$ was prepared by arc-melting and annealing, while the single crystal was grown by the Czochralski pulling method for $CeNi_2Al_5$. The residual resistivity ρ_0 and the residual resistivity ration RRR $(= \rho_{RT}/\rho_0)$ were $\rho_0 = 1.5\,\mu\Omega\,cm$ and $RRR = 220$ in $CeNiGe_3$, and $\rho_0 = 1.8\,\mu\Omega\,cm$ and $RRR = 160$ in $CeNi_2Al_5$, indicating high quality of the present samples. To apply high pressures, we used the indenter cell up to 4 GPa and the cubic anvil cell up to 8 GPa for both compounds. In addition, we used the diamond anvil cell up to 10 GPa for $CeNiGe_3$.

Fig. 1 shows the temperature dependence of the electrical resistivity at a typical pressure 6.5 GPa, which was obtained by using the diamond anvil cell. The electrical resistivity at ambient pressure has a broad hump around 100 K and also a broad peak around 8 K, and decreases steeply below $T_N = 5.5\,K$. With increasing pressure, T_N increases gradually, has a maximum at about 3 GPa and disappears at $P_c \simeq 5.5\,GPa$, as shown in the inset of Fig. 1.

The overall temperature dependence of the electrical resistivity at 6.5 GPa is characteristic as in the heavy fermion compound. The low-temperature resistivity follows the Fermi liquid relation of $\rho = \rho_0 + AT^2$. The A and ρ_0 values have a maximum around P_c. For example, the A value at 5 GPa, $10.5\,\mu\Omega\,cm\,K^{-2}$ is the same as that in a heavy fermion superconductor $CeCu_2Si_2$ [3]. Moreover, a sudden drop at $T_{sc} = 0.48\,K$ in Fig. 1 indicates an onset of superconductivity. Superconductivity was observed in a pressure range from 4 to 10 GPa, as shown in the inset of Fig. 1 [4], where T_{sc} is enlarged three times.

Fig. 2 shows the temperature dependence of the electrical resistivity under several pressures in

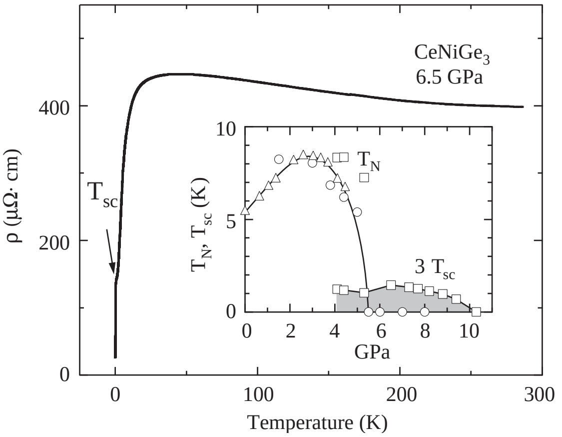

Fig. 1. Temperature dependence of the electrical resistivity at 6.5 GPa in $CeNiGe_3$. Inset shows the pressure dependence of T_N and T_{sc}, obtained by the cubic anvil cell (circles), the indenter cell (triangles), and the diamond anvil cell (squares).

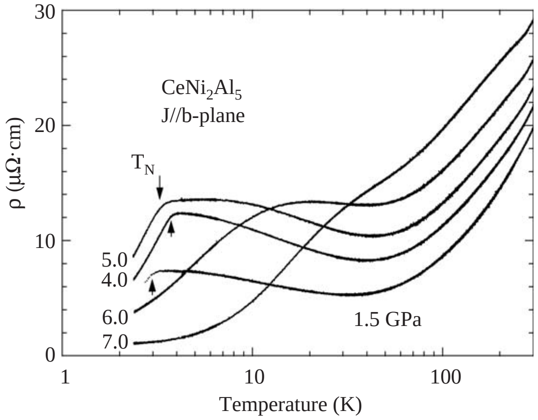

Fig. 2. Temperature dependence of the electrical resistivity under several pressures in $CeNi_2Al_5$.

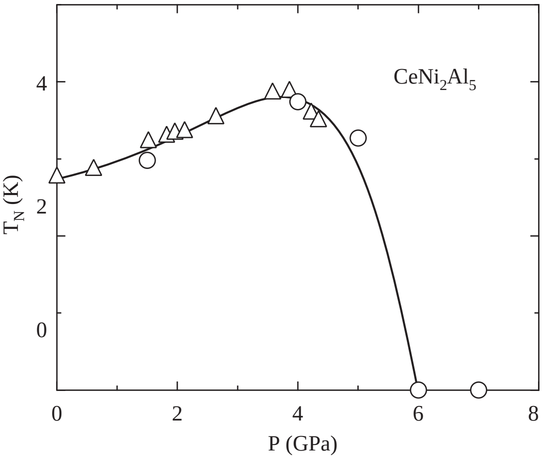

Fig. 3. Pressure dependence of T_N, obtained by the cubic anvil cell (circles) and the indenter cell (triangles) in $CeNi_2Al_5$.

$CeNi_2Al_5$ on a logarithmic scale. At 1.5 GPa, $\rho(T)$ shows the behavior of $-\log T$ below 25 K, indicating the characteristic Kondo effect. It also shows a sudden drop at $T_N = 3.0$ K, corresponding to an antiferromagnetic ordering. With increasing pressure, the magnitude of the resistivity itself increases slightly and the corresponding electronic state changes as a function of pressure.

We show in Fig. 3 the pressure dependence of T_N, obtained by the cubic anvil cell and also the indenter cell. T_N increases with increasing pressure, has a maximum around 4.0 GPa and decreases steeply with further increasing pressure. The antiferromagnetic ordering disappears most likely at 6.0 GPa.

The electrical resistivity around a critical pressure $P_c \simeq 5.5$ GPa in $CeNiGe_3$ is thus characteristic as in the heavy fermion superconductor $CeCu_2Si_2$, which is in contrast with the resistivity at a critical pressure $P_c \simeq 6.0$ GPa in $CeNi_2Al_5$. Superconductivity in $CeNiGe_3$, which is most likely responsible for a magnetically mediated d-wave type, is found to be realized in the heavy fermion state with the extremely large A and ρ_0 values of the resistivity of $\rho = \rho_0 + AT^2$.

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