NMR Study of Non Fermi Liquid System Sc_{1-x}U_xPd₃

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Abstract

We have performed ⁴⁵Sc NMR measurements on the Sc_{1-x}U_xPd₃ system, which exhibits an unconventional Kondo effect with a non-Fermi liquid character at low temperatures for the samples with $x \le 0.3$. The relaxation rates, $1/T_1$, for the x=0.3 and 0.25 samples are strongly enhanced by magnetic fluctuations below 30 K in low magnetic field, where other macroscopic properties show typical NFL behavior. Since the x=0.2 samples show Korringa $(T_1T=const.)$ behavior, this enhancement in the x=0.3 and 0.25 samples may be associated with an unusual electronic state near the quantum critical point. Below 1 K, T_1 in the x=0.3 sample seems to obey a $1/T_1 \propto T$ relation. This behavior may be associated with the enhanced Korringa relation in the vicinity of the quantum critical point.

 $\mathit{Keywords:}\ \mathrm{non}\ \mathrm{Fermi}\ \mathrm{liquid}\ (\mathrm{NFL});\ \mathrm{NMR};\ \mathrm{Spin-lattice}\ \mathrm{relaxation}\ \mathrm{time}$

 $Sc_{1-x}U_xPd_3$ ($0 < x \le 0.3$) is one of the Kondo non-Fermi liquid (NFL) systems and shows typical NFL behaviors of the electrical resistivity ρ , specific heat C/T and magnetic susceptibility χ as 1 - aT, $-\ln T$ and $1 - T^{1/2}$, respectively, where a is a positive or negative coefficient [1,2]. Theoretically, three models for NFL systems have been proposed so far; the multichannel Kondo effect, zero–temperature magnetic transitions and a distribution of Kondo temperatures. We measured the spin-lattice relaxation time, T_1 , of ${}^{45}Sc$ in $Sc_{1-x}U_xPd_3$ (mainly in x=0.3) to investigate the ground state of NFL systems from a microscopic point of view.

NMR measurements were performed by using a conventional pulsed spectrometer and a magnet $(0.5\sim4 \text{ T})$. T_1 of 45 Sc nuclei was measured by a comb pulse method.

At high temperatures, $1/T_1$ in the x=0.3 sample obeys the Korringa relation, which is simple metal-like behavior, with a little larger value of T_1T than that for x=0 sample [3], as shown in Fig. 1. This means that the density of states of the conduction electrons around the Sc nuclei and/or the hyperfine coupling constant between the conduction electrons and the Sc nuclei decreases with U doping. In x=0.3 sample the recovery can be fitted with the short and the long relaxation times (T_{1S} and T_{1L}) below 40 K. The ratio of the short and the long components in the recovery curve stays almost constant over the entire temperature range within an experimental error. This is probably ascribed to the inhomogeneous distribution of U around Sc atoms. In other words, the short and the long components of the recovery are probably coming from Sc with the strong and the weak magnetic fluctuations, respectively. T_{1S} does show temperature independence below 40 K (Fig. 1). This behavior is probably due to the relaxation by the local exchange field from the magnetic moment of U.

The temperature dependence of the long component of the recovery (T_{1L}) for the x=0.3 shows complex behavior. $1/T_{1L}$ is nearly T independent between 2 K and 20 K, where typical NFL behaviors were observed in ρ , C/T and χ . In order to investigate this T dependence, magnetic field dependence of the recovery was measured in the field of 0.5 T, 1 T and 4 T above 4.2 K. Relaxation rate taken at 4 T is longer than those of others. Since



Fig. 1. Temperature dependence of the relaxation rate $(1/T_1)$ of Sc NMR in Sc_{0.7}U_{0.3}Pd₃. The short $(T_{1\rm S})$ component of the T_1 in 0.5 T is indicated by closed square. The long $(T_{1\rm L})$ components of the T_1 in 0.5 T and 4 T are indicated by closed and open circles, respectively. The dashed line represents the Korringa like behavior in the x=0 sample.

this suppression in the relaxation process under a strong magnetic field of 4 T is observed, magnetic fluctuations of U 5f moments are considered to be dominant for this relaxation process in this temperature range. As this $(T_{1L}=const.)$ behavior observed just in the x=0.25 and x=0.3 samples was not found in the x=0.2 sample, the electronic states in the x=0.25 and 0.3 samples are near the quantum critical point (QCP). As shown in Fig. 1, the behavior of $T_{1L}\simeq const.$ is not in agreement with the calculations of Sengupta *et al.* $(1/T_1 \propto T^{1/4})[4]$ or of Tsvelik *et al.* $(1/T_1 \propto T^{1/3})[5]$. The reason of this discrepancy should be discussed in the future.

The relaxation shows a Fermi liquid-like behavior below 1.5 K. This behavior $(1/T_{1L} \propto T^1)$ is very close to the Korringa rule. It seems to be due to magnetic ordering which is observed in the x=0.4 sample. But no magnetic ordering occurs in x=0.3, because the signal intensity increases continuously as the temperature decreases. This Korringa like behavior may be associated with the QD₂ region, which shows Fermi-liquid behavior, discussed by Sengupta *et al.*[4].

In conclusion, T_1 of the Sc NMR was measured

between 0.37 K and 300 K in field of 0.5 T to 4 T in the x=0.3 sample. Above 40K, the relaxation was described with a single relaxation time and behaves like a simple metal. Below 40 K, the relaxation was fitted by two relaxation times. T_{1S} is temperature independent below 40 K and T_{1L} is temperature independent between 20 K and 2 K. This behavior is due to magnetic fluctuations from the U atoms. However, the temperature dependence can not be explained by theoretical calculations at present. Below $1.5 \text{ K}, T_{1L}$ shows a Korringa like behavior, which may be associated with the ground state realized near QCP. Similar behavior is also observed in the x=0.25 sample. In these samples, two electronic states exist; one of them, which feels strong magnetic fluctuation form U atoms, shows the short relaxation time, the other, which feels weak magnetic fluctuation, shows the long relaxation time and fall into the Fermi-liquid like state at low temperatures. These two features may be essential in the NFL state of $Sc_{1-x}U_{x}Pd_{3}$ system. Further measurements on the x=0.25 sample are in progress.

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