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NMR study of Ferromagnetic Kondo-lattice Skutterudite Compounds

T. Mito[1], S. Masaki[1], N. Oki[1], S. Wada[1], N. Takeda[2], H. Sugawara[3], D. Kikuchi[4] and H. Sato[4]

[1]Faculty of Science, Kobe University, Kobe 657-8501
[2]Faculty of Engineering, Niigata University, Niigata 950-2181
[3]Faculty of Integrated Arts and Sciencies, Tokushima University, Tokushima 770-8502
[4]Graduate School of Science, Tokyo Metropolitan University, Hachioji 192-0397

Some of filled skutterudite compounds exhibit both the Kondo effect and ferromagnetic ordering at low temperatures, and have attracted much interest. For example, $SmOs_4Sb_{12}$ is a ferromagnetic heavy-fermion compound with the electronic specific heat coefficient $\gamma = 0.82$ J/mol K^2 and magnetic ordering temperature $T_C \sim 3$ K [1]. Interestingly the γ value does not show any significant field dependence. As related compounds, we have investigated $SmFe_4P_{12}$ ($T_C = 1.6$ K and $\gamma = 0.37$ J/mol K^2) and $NdRu_4P_{12}$ ($T_C = 1.6$ K) by using the ^{31}P-NMR (nuclear magnetic resonance) technique.

In $NdRu_4P_{12}$, the resistivity ρ shows a minimum around 12 K, followed by a slight increase, which is attributed to the Kondo effect. Below T_C, ρ exhibits a rapid decrease [2]. Figure 1 shows the temperature dependence of the spin-lattice relaxation rate $1/T_1$ measured at $H \sim 0.3$ T (the NMR frequency $f = 5.1711$ MHz) and $H \sim 1.24$ T ($f = 21.3701$ MHz). At $H \sim 0.3$ T, $1/T_1$ shows weak temperature dependence down to 3 K without showing any fermi liquid like behavior, *i.e.* $1/T_1 \propto T$. This indicates that the T_1 relaxation process above T_C is dominated by the spin fluctuations of well localized 4f electrons, The rapid decrease in $1/T_1$ below 2 K is due to the ferromagnetic ordering. The onset temperature of the rapid decrease increases with increasing field (~ 7 K at $H \sim 1.24$ T). This is well consistent with field effect on ρ at low temperatures [2]. Besides, the values of $1/T_1$ above T_C are largely suppressed at $H \sim 1.24$ T. These phenomena indicate that low energy magnetic fluctuations are easily suppressed by small magnetic field. We will discuss the spin dynamics in $NdRu_4P_{12}$ by comparing with the results on $SmFe_4P_{12}$.

[1] S. Sanada *et al.*, J. Phys. Soc. Jpn. **74** (2005) 246.
[2] H. Sugawara *et al.*, JPS Spring Meeting (2006).

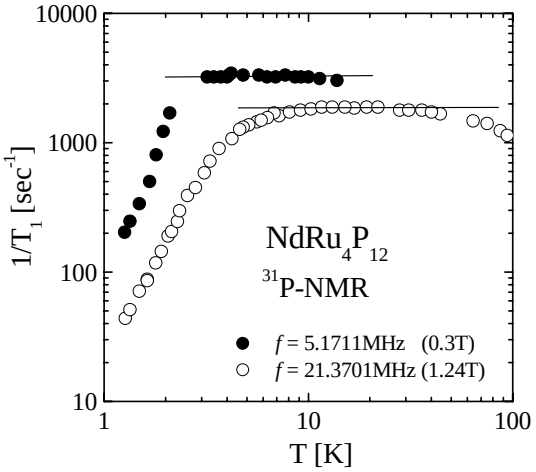

Figure 1: Temperature dependence of $1/T_1$ in $NdRu_4P_{12}$.