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Spin Dynamics of Pr-$4f$ Moments in $PrFe_4P_{12}$ and $PrOs_4Sb_{12}$ Revealed by NMR Study

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NMR studies have been carried out to investigate magnetic properties, especially the mechanism of the heavy-fermion (HF) state in Pr-based filled-skutterudite compounds. In this presentation, magnetic fluctuations in the paramagnetic state of $PrFe_4P_{12}$ and $PrOs_4Sb_{12}$ is discussed. In $PrFe_4P_{12}$, nuclear spin-lattice relaxation rate ($1/T_1$) above the AFQ ordering temperature shows the typical behavior of Kondo systems observed in Ce and Yb compounds. Using experimental results of $1/T_1$ and bulk susceptibility, the characteristic energy Γ of spin fluctuations by Pr-$4f$ moments (S) is derived. $\Gamma(T)/k_B$ varies proportionally to T between 50 and 125 K, which is anticipated for the scattering of the independent Pr-$4f$ local moments by conduction electrons (σ) via direct interaction $J_{cf}\sigma S$. The resistivity and $1/T_1$ results suggest the occurrence of local-moment screening below 50 K by the "*magnetic Kondo effect*". If the impurity-Kondo model discussed in Ce^{3+} and Yb^{3+} of HF compounds by Cox *et al.* is applied to the interpretation of temperature dependence of Γ, T_0 related to the Kondo temperature is estimated as $T_0 \sim 6.5$ K from the fitting of the experimental data to a theoretical curve. We suggest that the HF state in $PrFe_4P_{12}$ is understood by the magnetic Kondo resonance picture which has been applied to ordinary Ce and Yb HF compounds.[1]

If the same discussion is applied to $PrOs_4Sb_{12}$, it is found that the temperature dependence of Γ in $PrOs_4Sb_{12}$ is stronger at higher temperatures above 40 K than that in ordinary HF compounds, such as $T^{1/2}$ and T-linear dependence seen in $PrFe_4P_{12}$. We consider that the strong temperature dependence is due to the thermal excited phonon induced by the rattling motion of the Pr atoms. Actually, similar temperature dependence is observed in $LaOs_4Sb_{12}$, in which the rattling motion by La atoms is pointed out. From the NMR experiments, we show the presence of anomalous fluctuations in ROs_4Sb_{12} (R = Pr and La), which is related to the rattling motion of the R ions.

Normal and superconducting states in $LaFe_4P_{12}$ are investigated by La- and P-NMR experiments. $1/T_1$ shows a distinct coherence peak just below T_c, followed by the exponential decrease in the superconducting state. In addition, the decease of the Knight shift is observed. These experimental results show clearly that $LaFe_4P_{12}$ is a conventional s-wave superconductor. Detailed experimental results are presented by Nakai at the poster session in this workshop.

[1] K. Ishida *et al.*, to appear in Phys. Rev. B.