Inelastic Neutron Scattering from the Heavy-Electron System $NdFe_4P_{12}$

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Rare-earth filled skutterudite compounds have been extensively studied in terms of strongly correlated electron phenomena. One of the topics is heavy electron state appearing in the system with two or more $4f$ electrons per rare-earth ion. $PrFe_4P_{12}$ with $4f^2$ configuration of Pr^{3+} is a typical example, which shows the Sommerfeld coefficient for electronic specific heat $\gamma = 1.4\mathrm{J/mol/K^2}$ and the clear $-\log T$ behavior of electrical resistivity (Y. Aoki *et al.*, Phys. Rev. B 65 (2002) 064446, H. Sugawara *et al.*, Phys. Rev. B 65 (2002) 134411). Our inelastic neutron scattering experiment revealed the quasielastic magnetic response indicating the strongly hybridized state (K. Iwasa *et al.*, Acta Physica Polonica B 34 (2003) 1117).

A similar $-\log T$ behavior is also found in $NdFe_4P_{12}$ with $4f^3$ configuration of Nd^{3+} (H. Sato *et al.*, Phys. Rev. B 62 (2000) 15125). However, it undergoes a ferromagnetic phase transition at $T_C = 1.9$ K and the magnitude of ordered magnetic moment was evaluated as $1.6\mu_B/\mathrm{Nd}$ (L. Keller *et al.*, J. Alloys and Compounds 323-324 (2001) 516), which is much larger than the typical heavy electron materials and seems not to be consistent with the singlet formation due to Kondo effect. Thus, the heavy electron behavior in electrical resistivity of $NdFe_4P_{12}$ with well-localized $4f$ electrons is a mysterious property. In order to investigate the $4f$ electron state of this material, we performed inelastic neutron scattering experiments.

The triple-axis spectrometer TOPAN (6G) and HER (C1-1) were adopted to measure energy spectra from a single-crystalline sample.

Figure 1 shows energy spectra at $\mathbf{Q} = (4\ 0\ 0)$ of $NdFe_4P_{12}$ as a function of temperature. Quasielastic intensities extending beyond 5 meV were detected. Because the intensity decreases with decrease of temperature, these intensities are considered to be come from structural fluctuation. In the typical heavy-electron systems, magnetic quasielastic intensities have been generally observed, due to interaction between the localized $4f$ electrons and conduction electrons. In this case, the intensity of broad response increases with decrease of temperature, as the Pauli paramagnetic susceptibility. The observed result of $NdFe_4P_{12}$ is completely opposed. As written in the other report of this volume, we observed similar phonon spectra in $PrRu_4Sb_{12}$ and $PrOs_4Sb_{12}$, in which the filled Pr ions vibrate with large amplitude within the surrounding large cage of Sb. The relaxation mode may be given by the strong interaction between the Pr-ion motion and the electronic state. If the observed quasielastic response in $NdFe_4P_{12}$ was also come from such electron-phonon coupling, the heavy electron behavior would relate with the observed structural fluctuation spectra. We have to continue the study to clarify the mechanism of appearance of the quasielastic intensity.

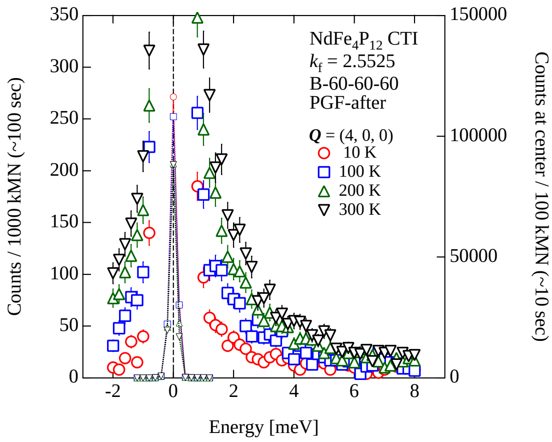

Fig. 1. Energy spectra at $\mathbf{Q} = (4\ 0\ 0)$ of $NdFe_4P_{12}$ as a function of temperature.