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Crystalline-electric-field effects of filled skutterudite and related f-electron systems

H. Amitsuka[1], A. Morishita[1], T. Wakabayashi[1], I. Kawasaki[1], Y. Ikeda[1], A. Gawase[1], Y. Hirozane[1], K. Matsuda[1], H. Hidaka[1], T. Yanagisawa[1], M. Yokoyama[2], and K. Tenya[3]

[1]Graduate School of Science, Hokkaido University, Sapporo 060-0810
[2]Faculty of Science, Ibaraki University, Mito 310-8512
[3]Faculty of Education, Shinsyu University, Nagano 380-8544

The effect of crystalline electric field (CEF) on local f electrons is fundamental and often crucial for our understanding of magnetic properties of rare-earth and actinide compounds. In this presentation, we report recent progress of our studies on the CEF effects in some filled skutterudites and so-called 122 and 3-20-6 compounds. In the filled skutterudites, hybridization of 4f with ligand p states may play an important role in the CEF splitting. It is theoretically found that in Pr skutterudites, if $4f^3$ configurations dominate over $4f^1$ as intermediate states, then the p-f hybridization favors the triplet ground state, while point-charge interaction favors the singlet [1,2]. We have studied single Pr-site properties of dilute magnetic alloys $Ce_{1-x}Pr_xM_4P_{12}$ (M = Fe, Ru; $x \leq 0.16$) by means of specific heat ($0.4\ \mathrm{K} \leq T \leq 40\ \mathrm{K}$; $\mathrm{B} \leq 12\ \mathrm{T}$) and magnetization ($2\ \mathrm{K} \leq T \leq 300\ \mathrm{K}$; $\mathrm{B} \leq 5.5\ \mathrm{T}$) measurements. The experimental results revealed that the low-energy CEF states of these alloys are described in terms of a triplet(0)-singlet(~ 20 K) level scheme, irrespective of the M ions. Since the hosts CeM_4P_{12} are insulators, the hybridization mast take place through the $4f^3$ intermediate level, creating a hole in the fully-filled a_u band. Our results are thus consistent with the theoretical prediction. The observation also indicates a fine splitting of the ground triplet, which might be important for the discussion of low-energy (< 1 K) phenomena in $PrRu_4P_{12}$ and $PrFe_4P_{12}$. Preliminary results on $Ce_{1-x}Sm_xRu_4P_{12}$, systematical studies of magnetic dilution for $La_{1-x}R_xRu_2Si_2$ (R = rare-earths and uranium; $x \leq 0.10$), and high-resolution neutron-scattering studies on $Pr_3Pd_{20}Ge_6$ will also be presented.

[1] J. Otsuki, H. Kusunose, and Y. Kuramoto, J. Phys. Soc. Jpn. **74** (2005) 200.
[2] Y. Kuramoto, et al., J. Phys. Soc. Jpn. **75** suppl. (2006) 209.