Observation of Quantized Muon Spin Precession Frequencies in Paramagnetic $PrPb_3$

T.U. Ito[1,2], W. Higemoto[1], K. Ohishi[1*], N. Nishida[2], R.H. Heffner[1,3], Y. Aoki[4], T. Onimaru[5], H.S. Suzuki[6], and A. Amato[7]

[1] *Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan*
[2] *Department of Physics, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan*
[3] *Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
[4] *Department of Physics, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan*
[5] *Department of Quantum Matter, ADSM, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8530, Japan*
[6] *National Institute for Materials Science, Tsukuba, Ibaraki 305-0047, Japan*
[7] *Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland*

We report μSR measurements in $PrPb_3$, where an antiferro-quadrupole ordering with long periodic structures has been found [1]. The muon localization site in $PrPb_3$ was identified to be $3d$ site, at the midpoint of two Pr ions, from the local symmetry probed by muon Knight shift [2]. Surprisingly, we observed spontaneous muon spin precession with five quantized frequencies in the paramagnetic state (Fig. 1), which suggests a strong coupling between the muon spin and the nearest neighbor ^{141}Pr nuclear spins, i.e., formation of spin entangled state ^{141}Pr-μ^+−^{141}Pr. The frequencies gradually increase with decreasing temperature and the lowest frequency reaches ∼3 MHz at 1.7 K. This behavior indicates that the μ^+ and ^{141}Pr nuclear spins are coupled not only through bare nuclear dipole interactions, but with the assistance of the $4f$ dipole moment induced by a strong intra-atomic hyperfine coupling. We will discuss the interplay of the $4f$ electrons and the positive charge of the implanted muon for the formation of a spin entangled state.

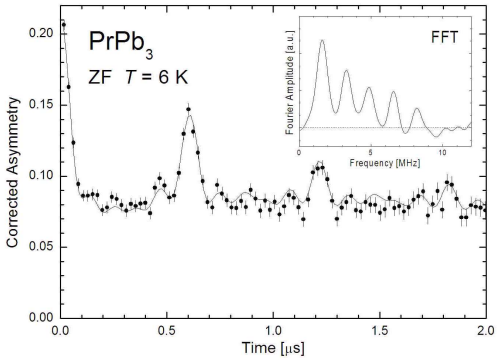

Fig.1 A typical ZF- SR spectrum in the paramagnetic state.

[1] T. Onimaru *et al.*, Phys. Rev. Lett. **94** (2005) 197201.
[2] T.U. Ito *et al.*, J. Mag. Mag. Mat. **310** (2007) 743-745.

* Present address: Advanced Meson Science Laboratory, RIKEN, Saitama 351-0198, Japan