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7.10 Repolarization of negative muons in polarized muonic ^{209}Bi atoms

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Although a negative muon (μ^-) is born 100 % polarized due to the 100 % parity violation in $\pi\to\mu\nu$ decay, it loses the polarization P_μ through the capture and transition processes of muonic atom in the matter[1]. The expected residual P_μ at the ground state is less than 16 % in zero spin nuclei, and it suffers another 1/3 reduction due to nuclear hyperfine field from non-zero spin nuclei. Furthermore, the small decay e^- asymmetry A (= A_0P_μ; A_0 being around 0.2 for heavy elements[2]) for bound μ^- makes it difficult to get any experimental information as to the P_μ in muonic atoms of heavy nuclei under the usual conditions.

In order to overcome the above mentioned difficulty, we developed a new method to restore the polarization of μ^- using polarized ^{209}Bi nuclear target. The principle is as follows. When a hyperfine coupling becomes larger than the natural width at a muonic state J, the μ^- forms polarized hyperfine $F^\pm$(=J±I) states with polarized nuclei[3] and reaches 1s doublet state through cascade process (J,I and F refer to angular momenta). Finally, the μ^- spin turns to the lower hyperfine state through M1 transition and becomes parallel (or antiparallel) with the nuclear spin[4-6]. Therefore, the lower hyperfine state is polarized even in the case of zero polarization of initial J state. Thus, if ~~we~~ can polarize the nuclear spin, we can repolarize the μ^- through the hyperfine interaction. The expected P_μ from the repolarization in the nuclei of spin I with polarization P_T is calculated as

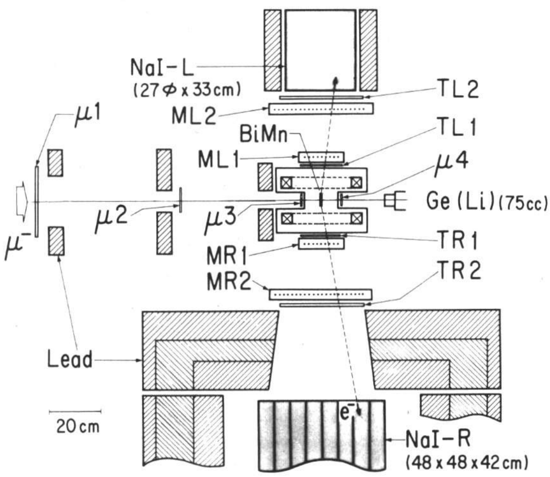

Fig. 1. Top view of experimental setup: μ, T and M refer to muon counters, electron counters and MWPC's.

$$P_\mu = C(I)P_T = -\frac{4I(I+1)(2I-1)}{(2I+1)^3}P_T = -0.792\ P_T \text{ for Bi } (I=9/2),$$

where the hyperfine interaction is assumed to be switched on at the 1s state[5,6]. If we do not take the final M1 transition into account, the coefficient C is so small as $4I/(2I+1)^2 = 0.18$.

For the polarized nuclei ^{209}Bi, a ferromagnetic compound of BiMn (T_c=633 K) was used because of the strong internal field on Bi nuclei from Mn atomic moments[7,8]. The external magnetic field of 6.4 KG (which is sufficient to fully magnetize the BiMn) produces hyperfine field of 1 MG on the Bi sites. The P_T of Bi was held to be 59±9 % through the runs of low temperature of 62±4 mK. Thus the expected repolarization P_μ of μ^- from target polarization is $P_\mu = CP_T \sim 50$ %, which is about ten times larger than the usual P_μ.

The experiment was done at the μE1 channel in SIN. The schematic view of the experimental set up is shown in Fig.1. Typically $2 \cdot 10^4$ μ^-/sec were stopped in the BiMn target (~250 g) which was polarized perpendicular to the μ^- beam (no beam polarization expected), and the time and energy spectra of decay e^- were measured. The trigger condition was

$$\text{Event}(e^-) = \mu 1 \cdot \mu 2 \cdot \mu 3 \cdot \mu 4 \cdot (\text{TL1} \cdot \text{TL2} \cdot \text{NaIL}) \text{ or } (\text{TR1} \cdot \text{TR2} \cdot \text{NaIR}).$$

In order to get a better signal to noise ratio, four planes of MWPC's were installed. A Ge(Li) detector was placed near to the target for a monitor of muonic X-rays from μ^- atomic capture.

To avoid systematic errors, we deduced asymmetry of decay e^- as

$$A_{exp} = \frac{N_R(62\text{mK})/N_R(4.2\text{K}) - N_L(62\text{mK})/N_L(4.2\text{K})}{N_R(62\text{mK})/N_R(4.2\text{K}) + N_L(62\text{mK})/N_L(4.2\text{K})},$$

where N_L or N_R denotes the number of each component (Bi, Mn etc.) obtained from the analysis of time spectra of Left side or Right side detector. We repeated four cycles of the measurements, each consisting of pairs of 62 mK and 4.2 K (no polarization) runs. The preliminary results of those four cycles are shown in Table 1. One of those cycles (cycle 3) was done under reversed magnetic field to see the opposite effect.

Combined with a Monte Carlo calculation of e^- acceptance, the experimental value of P_μ from the A_{exp} ($=P_\mu^*$) is deduced as shown in Table 1. Compared with the predicted value P_μ, the agreement is quite satisfactory and the results are consistent with the present theoretical assumptions. Thus we conclude that the μ^- was polarized up to 50 % by our repolarization technique.

Table 1. Summary of results (preliminary)

Cycle	$\vec{P}$	A_{exp}(Bi) (%)	$P_\mu^* / \vec{P}$ (%)
1	+	+ 7.03 ±4.42	− 46 ±29
2	+	+ 8.73 ±3.11	− 77 ±39
3	−	− 6.91 ±4.44	− 51 ±32
4	+	+ 8.04 ±4.53	− 70 ±40
		average	− 61 ±18
		P_μ	− 47 ± 7

$\vec{P}$ denotes the direction of target (Bi) polarization.

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