Proc. Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985
J. Phys. Soc. Jpn. 55 (1986) Suppl. p. 1040-1041

7.11 Atomic Cascade Effect on μ^- Repolarization in Polarized ^{209}Bi

Y. Kuno, K. Nagamine and T. Yamazaki

Meson Science Laboratory and Department of Physics,
Faculty of Science, University of Tokyo,
Hongo, Bunkyo-ku, Tokyo 113, Japan

There have been considerable interests concerning polarization phenomena in nuclear muon capture for the studies of weak interaction; such as asymmetric distributions of neutrons, these of γ-rays in radiative capture and hyperfine effects on nuclear muon capture rates, and so on[1]. However, these attempts have been faced with large difficulties due to the small residual polarization of muons at the 1s state of muonic atom; i.e. negative muons lose about 5/6 of their polarization at the atomic capture and cascade process down to the 1s state of the muonic atoms[2]. For muonic atoms of nuclei with a non-zero nuclear spin, muons get additional depolarization owing to the hyperfine interaction between nuclear spins and muon spins[3]. In order to recover the residual polarization of muonic atoms, Nagamine and Yamazaki[4] proposed the artificial negative-muon polarization by using a polarized nuclear target of ^{209}Bi in a magnetic compound of BiMn. Recently, the first experiment has been successfully carried out[5].

The mechanism of repolarization by hyperfine coupling with polarized nuclei was already discussed[6,7] and is similar to the well-known Overhauser effect. Furthermore, the importance of the hyperfine conversion process was strongly stressed[8]. However, so far, theoretical estimations on the repolarization have been limited to the assumption that the hyperfine interaction is switched on immediately at the instance when muons reach the 1s state of muonic atom. In this letter, we consider the atomic cascade effect on the repolarization mechanism, especially, for the case of muonic ^{209}Bi atom $(I=9/2, \mu_N=4.07)$.

The calculation was based on the statistical-tensor approach,[6,8] and the following assumptions were adopted; (1) all the cascade processes are subject to radiative E1 transitions, (2) no effect of nuclear level mixings is involved, (3) the effect of energy splitting of the fine and hyperfine structure (at most 5 keV) is neglected for the E1 transition probability, (4) the difference of the radial wave functions of these splittings is not taken into account, and (5) only the cascades through circular orbits are considered.

When fine splitting states $(J=L\pm1/2)$ in muonic atoms are coupled with the nuclear spin (I), the statistical-tensors of the hyperfine states F (F=I+J) are expressed by

$$B_k(F)=\frac{(2F+1)^{3/2}(2k+1)^{1/2}}{(2J+1)^{1/2}(2I+1)^{1/2}}\begin{Bmatrix} I & J & F \\ I & J & F \\ k_1 & k_2 & k \end{Bmatrix} B_{k_1}(I)B_{k_2}(J), \tag{1}$$

where $B_k(J)$, $B_k(I)$ and $B_k(F)$ are the statistical tensors of the rank of k for the spin states in muonic state, nucleus and hyperfine state, respectively. When evaluating $B_1(F)$, the coupling of the nuclear alignment and the muon polarization, namely $B_1(J)B_2(I)$, is taken into account in this calculation, together with $B_1(J)B_0(I)$ and $B_0(J)B_1(I)$. The cascade processes between hyperfine states are calculated in terms of the extended U-coefficients (U^*) presented by

$$U^*(LL'JJ'FF'I1) = (2L+1)(2J'+1)[W(LL'JJ';1\tfrac{1}{2})]^2 \times$$
$$(2J+1)(2F'+1)[W(JJ'FF';1I)]^2 \times U(F1F') \tag{2}$$

for the E1 transition from the state of (L,J,F) to (L',J',F'), where U is the well-known usual U-coefficient[10]. The hyperfine conversion process from F=5 to F=4 at the 1s state of muonic atom was taken into account. The residual polarization of muons, P_μ, obtained by projecting the polarization of the lowest hyperfine state (F=4) to the initial muon-spin direction, is presented in a simple form as follows;

$$P_\mu = - [C_T \times P_T + C_\mu \times P_0 + C_A \times A_T P_0], \tag{3}$$

where C_T, C_μ and C_A refer to the coefficients of the polarization transfer to the μ^- polarization from the target polarization (P_T), from the initial muon polarization before atomic capture (P_0), and from the coupling of target alignment (A_T) and muon polarization. Here, we assume the polarization of muons at the fine structure doublets (J=L±1/2) equal to ± 1/3 P_0[2]. The results are summarized in Table.1, where the transfer coefficients are presented against the muonic state from which the hyperfine splitting is switched on. It is clearly shown that C_T decreases by the cascade effects from higher hyperfine states, while C_μ and C_A increase.

In conclusion, we demonstrate that the atomic cascades from the higher hyperfine states reduce slightly the amount of polarization-transfer from the polarized nuclear target. Moreover, the coupling of the muon polarization with the alignment of the target nuclei contribute slightly to the additional polarization. The comparison with the experimental results will give us important information on the muonic cascade mechanism; namely, from which muonic level the hyperfine splitting is switched on? The present calculation will also be useful to explain the residual polarization measured by negative-muon spin rotation method in case of non-zero nuclear spin[10].

Table I. Summary of the cascade calculations

h.f state switched from	C_T	C_μ	C_A
1s state	0.7920	0.0071	0.0033
2p state	0.7496	0.0277	0.0100
3d state	0.6884	0.0486	0.0147

References

1) N.C. Mukhopadyay: Phys. Rep. 30C (1977) 1 and references therein.
2) R.A. Mann and M.E. Rose: Phys. Rev. 121 (1961) 293.
3) H. Überall: Phys. Rev. 114 (1959) 1640
4) K. Nagamine and T. Yamazaki: TRIUMF Experimental Proposal No.73 (1975)
5) R. Kadono et al.: contribution to this conference
6) K. Nagamine and T. Yamazaki: Nucl. Phys. A219 (1974) 104,
7) L. Hambro and N.C. Mukhopadhyay: Phys. Lett. 68B (1977) 143, N.C. Mukhopadhyay and A. Hintermann: Phys. Lett. 86B (1979) 137
8) T. Yamazaki: Nucl. Phys. A335 (1980) 537
9) e.g. see H. Morinaga and T. Yamazaki : "In-beam Gamma-ray spectroscopy"
10) D. Favart et al.: Phys. Rev. Lett. 25 (1970) 1348