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GAMMA-NEUTRINO CORRELATION IN MUON CAPTURE IN ^{14}N

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It was suggested the investigation of the gamma-neutrino angular distribution in the process

$$^{14}N(1^{+}) \xrightarrow{\mu^{-}} {}^{14}C^{*}(2^{+}) \xrightarrow{\gamma} {}^{14}C(0^{+}) \qquad (1)$$

in order to determine the magnitude of induced pseudoscalar term C_P /1/x/ but the additional nuclear matrix elements (M.E.) were neglected there. The aim of this paper is to pay attention to the necessity of the account of the M.E. of the second forbidden transition (cf./3/). We want to stress that in all effects where appears the interference between the different forbiddennesses, the restriction to the terms of one forbiddenness only is not justified. The classification of Morita and Fujii/4/ in these cases can not be applied.

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x/ Grenacs et al./2/ have proposed a method for measurement of the angular correlations in muon capture process with the excited daughter nuclei.

It was shown experimentally the existence of the conversion between the hyperfine (hf) K-shell levels of the mesic atom for some nuclei[5]. Then the muon capture rate and the coefficients of angular correlations will depend in general on the time[1,5,6]. Because the ^{14}N nucleus has a positive magnetic moment then the capture rate $\Lambda^{c}(t)$ from the statistical populated hf levels $(t=0)$ considerably exceeds the capture rate from the lower hf state $(t\to\infty)$. It can be expected that for the large conversion rate R the correlation coefficients $a_s(t)$ will change strongly with the time[1]. The general form of the gamma-neutrino correlation for (1) looks as follows

$$W = 1 + a_2(t)P_2(\vec{k}\vec{q}) + a_4(t)P_4(\vec{k}\cdot\vec{q}). \tag{2}$$

We denote by $\vec{k}$ and $\vec{q}$ the unit vectors in the direction of gamma quantum and neutrino momenta respectively. The coefficients $a_s(t)$ depend on the time in the following way[1]

$$a_s(t)\Lambda(t) = a_s^{-} + (a_s^{stat} - a_s^{-})\exp(-Rt), \tag{3}$$

$$\Lambda(t) = \Lambda^{-} + (\Lambda^{stat} - \Lambda^{-})\exp(-Rt). \tag{4}$$

Here Λ^{-}, a_s^{-} and Λ^{stat}, a_s^{stat} describe the capture from the lower hf level and from the statistical populated hf levels respectively. For the capture rate (1) we have

$$\Lambda^{c}(t) = \frac{40}{27}(\alpha Zm)^3 q^2 \Lambda(t), \tag{5}$$

where we denoted by m the reduced muon mass and by q the energy of a neutrino. For the process (1) we obtain

$$\Lambda^{stat} = P_1^2 + 2M_1^2 + \frac{1}{7}\left(\frac{3}{2}A_2^2 + V_2^2 + 3P_3^2 + 4M_3^2\right)$$

$$a_2^{stat} = \frac{1}{2}\left(P_1^2 - M_1^2 - \sqrt{\frac{15}{7}}M_1A_2\right) + \frac{\sqrt{2}}{7\sqrt{7}}(3M_1M_3 + 4P_3P_1) +$$

$$+ \frac{12}{49}\left[\frac{5}{96}(3A_2^2 + 4V_2^2) + \sqrt{\frac{5}{6}}A_2M_3 + P_3^2 + M_3^2\right] \qquad (6)$$

$$a_4^{stat} = -\frac{8}{7}\sqrt{\frac{2}{7}}(P_1P_3 - M_1M_3) -$$

$$-\frac{8}{147}\left(A_2^2 - V_2^2 + \frac{5}{2}\sqrt{\frac{5}{6}}A_2M_3 + \frac{3}{2}P_3^2 + \frac{1}{3}M_3^2\right)$$

$$\Lambda^- = (M_1 - P_1)^2 - \sqrt{\frac{3}{35}}(M_1 - P_1)(3A_2 + 2V_2) + \frac{1}{4}A_2^2 +$$

$$+ \frac{1}{7}(A_2 + V_2)V_2 + \frac{1}{21}(4M_3 + 3P_3)\left[2\sqrt{\frac{6}{5}}(A_2 - V_2) + 4M_3 + 3P_3\right]$$

$$a_2^- = \frac{1}{2}(M_1 - P_1)^2 - \frac{5}{14}\sqrt{\frac{3}{35}}(M_1 - P_1)\left[5A_2 + 2V_2 + \sqrt{\frac{2}{15}}(4M_3 + 3P_3)\right] +$$

$$+ \frac{1}{147}\left[\frac{15}{2}\left(\frac{13}{4}A_2^2 + A_2V_2 + V_2^2\right) + \sqrt{\frac{5}{6}}(5A_2 - 2V_2)(4M_3 + 3P_3) + 4(4M_3 + 3P_3)^2\right]$$

$$a_4^- = \frac{8}{147}\left\{\sqrt{14}(M_1 - P_1)\left[\sqrt{\frac{6}{5}}(A_2 - V_2) + 4M_3 + 3P_3\right] - \right. \qquad (7)$$

$$-(A_2 - V_2)(2A_2 + V_2) -$$

$$-\frac{1}{\sqrt{30}}(11A_2 + 4V_2)(4M_3 + 3P_3) -$$

$$\left. -\frac{1}{6}(4M_3 + 3P_3)^2\right\},$$

where neglecting terms of the order of αZ we have

$$A_I = -\sqrt{I(2I+3)}\left\{ G_A [1II] + \frac{C_V}{M\sqrt{2I+1}}\left(\sqrt{I+1}\,[1I-1I_p] - \sqrt{I}\,[1I+1I_p]\right)\right\}$$

$$V_I = \sqrt{3(I+1)(2I+3)}\left\{ G_V [0II] - \frac{C_V}{M\sqrt{3(2I+1)}}\left(\sqrt{I}\,[1I-1I_p] + \sqrt{I+1}\,[1I+1I_p]\right)\right\}$$

$$M_I = \sqrt{\frac{I}{I+1}}\left\{ G_A\left(\sqrt{I+1}\,[1I-1I] - \sqrt{I}\,[1I+1I]\right) - \sqrt{2I+1}\,\frac{C_V}{M}[1II_p]\right\} \tag{8}$$

$$P_I = (G_A - G_P)\left(\sqrt{I}\,[1I-1I] + \sqrt{I+1}\,[1I+1I]\right) + \sqrt{3(2I+1)}\,\frac{C_A}{M}[0II_p].$$

Here [1II] etc. are M.E. defined by Morita and Fujii [4], I is the total angular momentum of the neutrino-muon system, G_i are effective coupling constants, C_V and C_A are the vector and axial vector constants respectively, M is the nucleon mass. Because of the second forbidden terms, the new constituent appears in (2) connected with $P_4(\vec{k}\vec{q})$, determined mainly by the interference of amplitudes of allowed $(I=1)$ and second forbidden $(I=2,3)$ transitions. Besides, these terms give the weak dependence of $a_2(\infty)$ on C_P x/.

As one can see from (6-7) the presence of the largest M.E. [101] in a_S^{stat}, Λ^- and a_S^- is caused mainly by induced interactions in particular by the pseudoscalar constant. Therefore the ac-

x/ If we restrict ourselves to the terms of allowed transition only then the conservation of angular momentum gives us the independence of $a_S(\infty)$ of the weak interaction Hamiltonian [1,3].

count of the forbidden M.E. can strongly influence the time dependence of $\Lambda^c(t)$ and $a_s(t)$ and the determination of the magnitude of C_P .

For the calculations of M.E. we used the intermediate coupling shell model assuming the transition in p-shell only and the harmonic oscillator radial wave function. For the nuclear wave function calculations, according to[7], we choose the following parameters: the amplitude of spin-orbital interaction $a = -5$ MeV, the ratio of radial integrals of pairing interaction $L/K = 6$, with K changing in the range from $K=0$ (i.e. jj coupling) to $K = -1.6$ MeV. The curves on Figs. 1-3 which take into account the additional M.E. are given for the presently accepted optimal value $K = -1.2$ MeV. The deviations of $a_s(t)$ and $\Lambda^c(t)$ caused by variation parameter K are denoted by the vertical dashes. These figures show clearly that the account of the interference of allowed and forbidden terms is necessary. Fig.1. demonstrates that the account of [122] , which is dominating among the second forbidden M.E. and still remains dominating among all additional M.E. (including allowed ones), is as essential as the account of the main allowed terms. We have obtained $[122] \approx -0.12\,[101]$. The contributions of the allowed additional M.E. can be practically neglected. The formula (6) predicts $a_4(0) \lesssim -0.01$ because in addition we have $[123] \approx -0.01[101]$. In the case of the capture from lower hf level the coefficient of $P_4(\vec{k}\vec{q})$ correlation $a_4(\infty)$ is more sensitive to C_P and to contribution of forbidden terms than $a_2(\infty)$. Fig.2 demonstrates that the account of forbidden terms changes essentially the time dependence of $a_2(t)$ in comparison to nuclear model independent approximation used in ref.[1]. The contribution of forbidden terms to the capture rate for $t = 0$ is very small ($\lesssim 3\%$) as was expected[4], but for $t \to \infty$ the account of the forbidden M.E. is very important (see fig.3).

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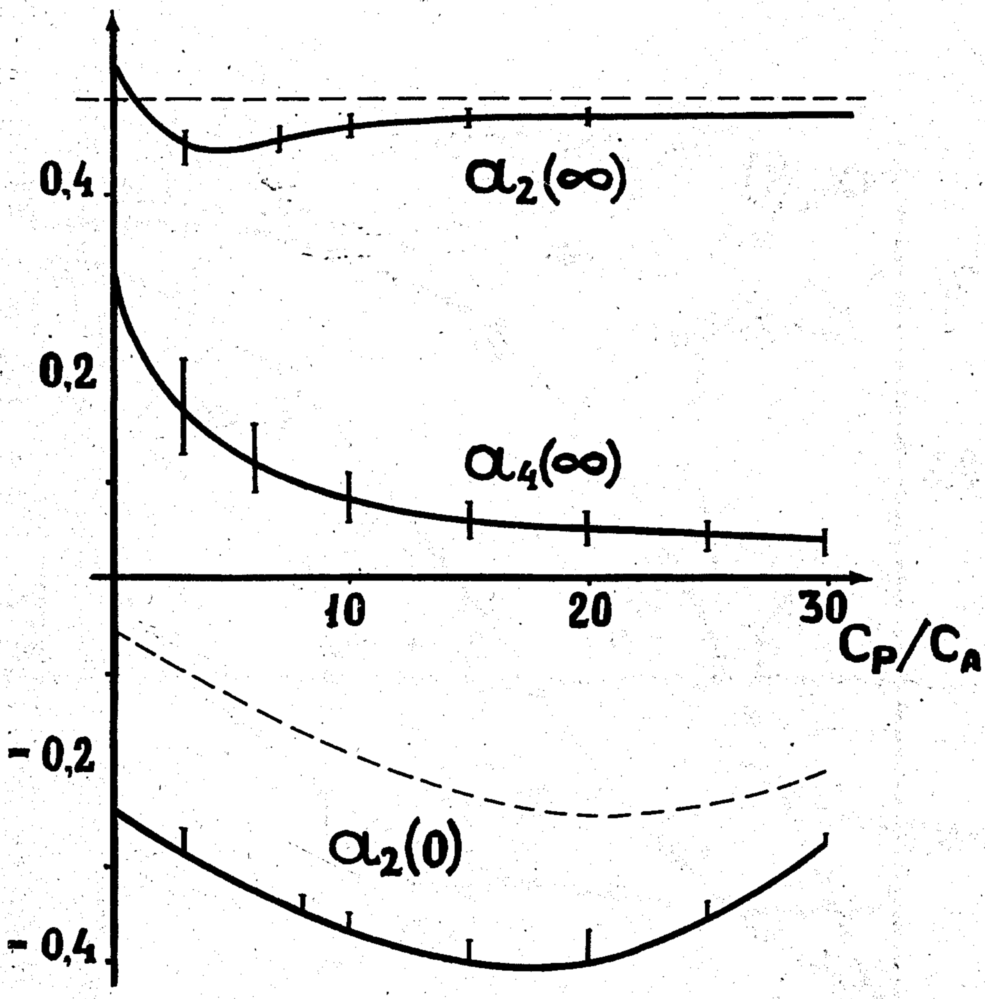

Fig.1. The coefficients $a_s(t)$ for the capture from the statistical populated hf levels $(t=0)$ and from the lower level $t \to \infty$ vs. C_P/C_A. The solid and dashed lines correspond to the inclusion of all additional M.E. and nuclear model independent approximation /1/ respectively.

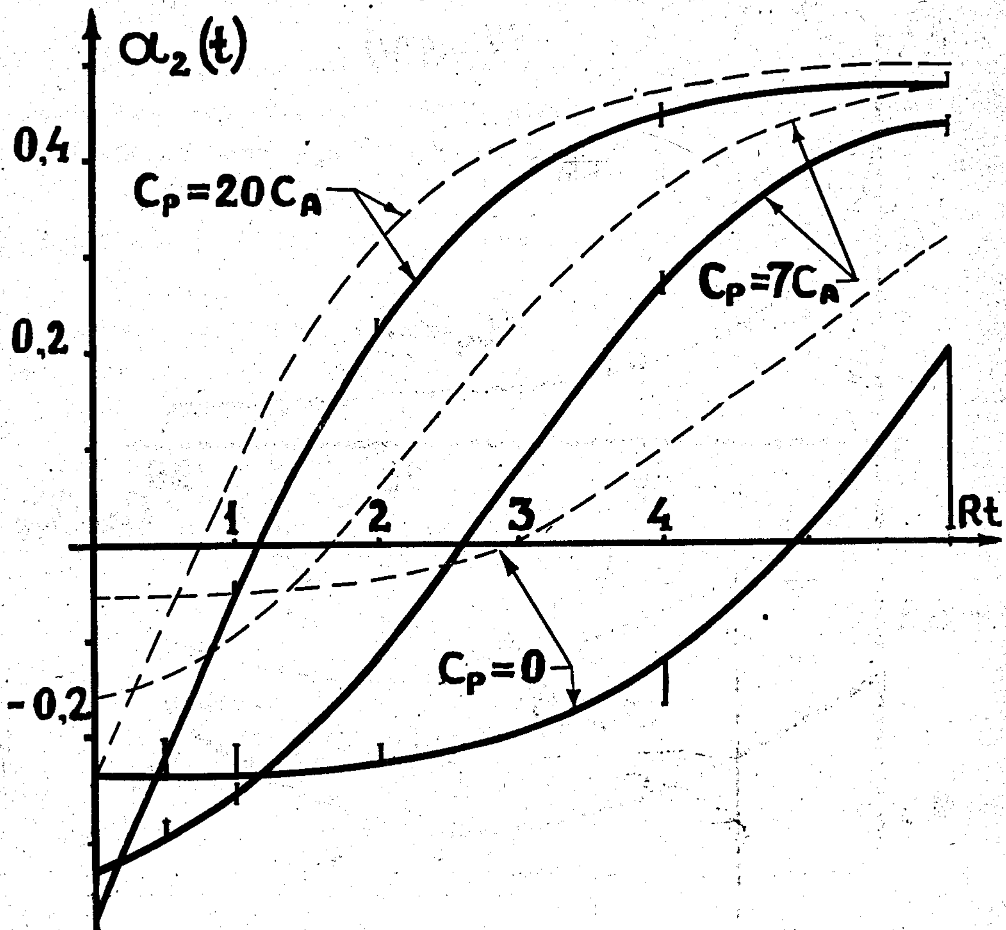

Fig.2. The time dependence of $a_2(t)$. The solid and dashed lines correspond to the inclusion and exclusion /1/ of all additional M.E. respectively.

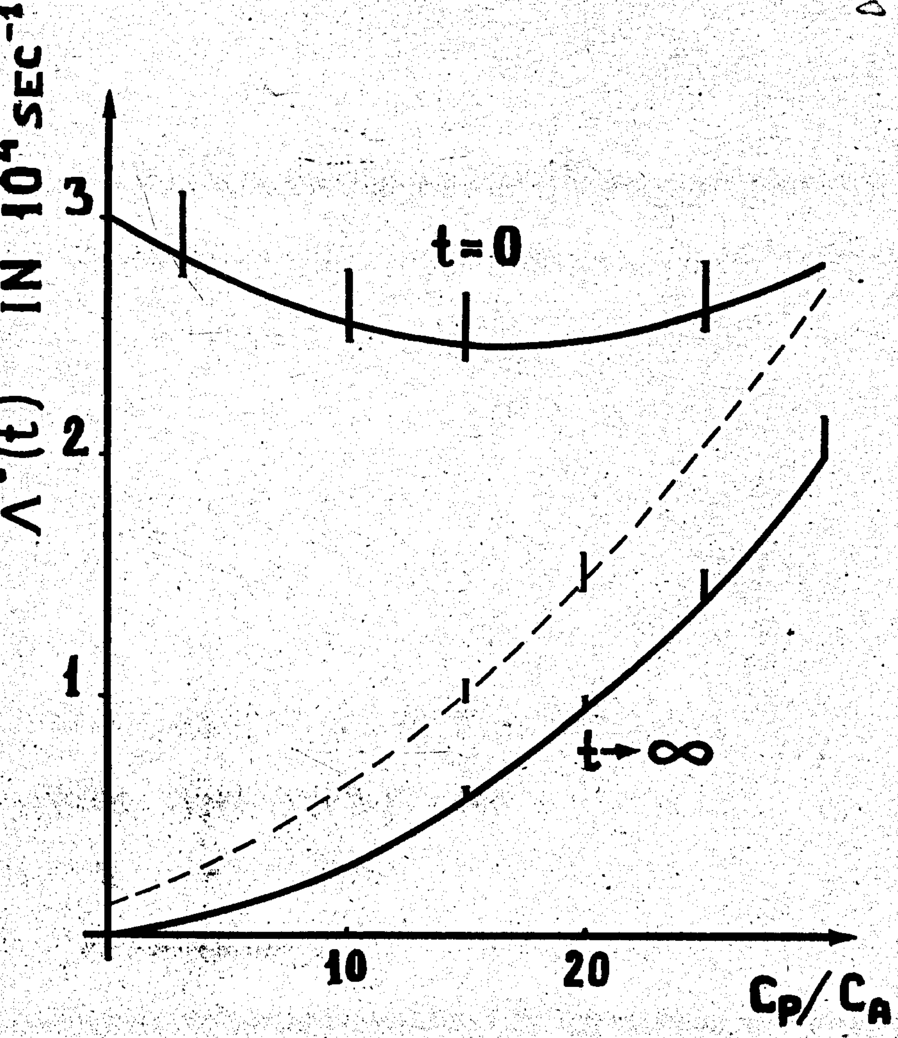

Fig.3. The capture rate $\mathring{\Lambda}(t)$ vs. C_P/C_A for $t=0$ and $t \to \infty$. The dashed line refers to the exclusion of forbidden terms for $t \to \infty$.