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Possible evidence for mesonic exchange correction in $^{16}\text{N}(0^-) \leftrightarrow ^{16}\text{O}(0^+) \beta$ -decay and μ -capture reactions

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It is shown that a particularly large mesonic exchange effect is to be expected for the two inverse processes muon-capture and β -decay concerning the transitions between the $^{16}\text{O}(0^+)$ ground state and the $^{16}\text{N}(0^-)$ excited state. It arises from a strong correction to the time part of the axial weak current. It is found that presently available experimental data can be qualitatively consistent with this picture.

Since the advent of meson theories there have been many attempts to exhibit mesonic effects in electromagnetic and weak nuclear processes. Efforts have been focused on reactions without nuclear complications. Successes were obtained in $n\text{p}$ radiative capture [1] and deuteron electrodisintegration [2] which are induced by vector currents. In these two cases meson exchange corrections were able to explain most of the discrepancy between experimental results and impulse approximation (IA) calculations. On the contrary, axial current processes did not give any clear-cut evidence for exchange corrections. However, most efforts were concentrated on reactions dominated by the space part of the current (β -decay and μ -capture in allowed transitions).

As emphasized by Kubodera et al. [3], a description of mesonic contributions limited to one pion exchange (OPE) should be much more reliable for the time part than for the space part of the axial current and could give rise to large effects.

In this note we investigate the following pure axial weak processes

$$^{16}\text{N}(0^-, 120 \text{ keV}) \rightarrow ^{16}\text{O}(0^+, \text{g.s.}) + e^- + \nu_e, \quad (1)$$

$$\mu^- + ^{16}\text{O}(0^+, \text{g.s.}) \rightarrow ^{16}\text{N}(0^-, 120 \text{ keV}) + \nu_\mu, \quad (2)$$

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which are known to be very sensitive to the time part of the current. Working in OPE approximation we shown they suffer such a huge modification from exchange currents that it should overcome nuclear uncertainties.

Explicit calculations [4] have shown that the space part of the OPE current is actually small (a few percent). So we shall neglect it in the following and treat the space part of the nuclear current in IA with the standard values of the nucleon axial form factors: $g_A = 1.23$ for beta decay and muon capture and $g_P = 7g_A$ for muon capture. Also second class currents have been assumed to be absent. The time part is deduced from the Adler–Dothan theorem [5] which is the current algebra prescription for the weak production amplitude of low-momentum pions. The derivation of the resulting operator has been given in a previous work [4]. In configuration space it reads:

$$h_{\pm}^{\text{II}} = \sum_{i \neq j=1}^A \left(-\frac{g_1^2}{8\pi g_A} \cdot \frac{m_\pi^2}{M^2} \right) \boldsymbol{\sigma}(j) \cdot \hat{r}_{ij} \times Y_1(m_\pi r_{ij}) [\boldsymbol{\tau}(i) \times \boldsymbol{\tau}(j)]_{\pm} \ell_{\pm}. \quad (3)$$

In formula (3), $\boldsymbol{\sigma}(i)$ and $\boldsymbol{\tau}(i)$ are the spin and isospin operators acting on the i th nucleon; r_{ij} is the distance between i and j ; $\hat{r} = \mathbf{r}/|\mathbf{r}|$; $Y_1(x) = (1 + 1/x) \cdot e^{-x}/x$; m_π and M are the pion and nucleon masses; $g_1^2/4\pi$ is the strong coupling constant (14.6). h_{\pm}^{II} refers to β -de-

cay and h^{II} refers to muon capture. ϱ_{\pm} is the time component of the leptonic current, h_{\pm}^{II} is added to the time part of the one-body operator:

$$h_{\pm}^{\text{I}} = \sum_{i=1}^A g_A \left(\frac{\boldsymbol{\sigma}(i) \cdot \mathbf{p}(i)}{M} - \frac{\boldsymbol{\sigma}(i) \cdot \mathbf{k}}{2M} \right) \tau^{\pm}(i) \varrho_{\pm}, \quad (4)$$

where $\mathbf{p}_i, \mathbf{r}_i$ are the momentum and position of the i th nucleon and \mathbf{k} the momentum transferred to the lepton. We define the ratio z_{\pm} :

$$z_{\pm} = (\langle h_{\pm}^{\text{I}} \rangle + \langle h_{\pm}^{\text{II}} \rangle) / \langle h_{\pm}^{\text{I}} \rangle, \quad (5)$$

where the brackets denote nuclear matrix element. In most computations the negative-parity state is described in the one particle–one hole approximation:

$$|0^{-}\rangle = (1 - X^2)^{1/2} |1p_{1/2}^{-1}, 2s_{1/2}\rangle + X |1p_{3/2}^{-1}, 1d_{3/2}\rangle. \quad (6)$$

In table 1 we give the values of z_{\pm} for $X = 0$ or 1. As can be seen, there is a huge effect. Perhaps more important, it is a nearly uniform enhancement ($\simeq 1.5$) for the two configurations and for the two processes. As a similar enhancement has been reported in the case of the allowed ^{12}B to ^{12}C β -decay [3] this can be taken as an indication that it is a rather “gross” effect qualitatively independent of the nuclear transition. This point of view is supported by calculations of the effective one-body time component operator [6].

An important point is the consequence of that mesonic correction on the observables: β -decay rate and μ -capture rate. Of course this consequence must be more drastic in β -decay because the time part dominates the matrix element. Indeed it is the case: the

Table 1

Renormalization coefficients z_{\pm} of the matrix element of the axial current time part for the two configuration mixing components of the 0^{-} state and the two processes.

	$1p_{1/2}^{-1}, 2s_{1/2}$	$1p_{3/2}^{-1}, 1d_{3/2}$
z_{+} (β^{-} -decay)	1.59	1.44
z_{-} (μ^{-} -capture)	1.59	1.47

β -decay 1A result including Coulomb corrections is multiplied by a factor 3 to 6 when X runs from -0.3 to $+0.3$. In muon capture the corresponding factor is about 1.7. Detailed results are given in table 2.

Hence the meson effect is so huge that it should overcome nuclear wave function uncertainties. This qualitative enhancement is the main result of this note. Reliable estimation of the rates should make use of more refined wave functions than the simple one particle–one hole (see e.g. ref. [7]). Furthermore, a more precise evaluation of electromagnetic corrections is needed in the case of β -decay: standard calculations indicate that they decrease the rate due to destructive interference between the space and time parts of the current; on the other hand recent claims [8] from the elementary particle method that they strongly increase the rate appear highly questionable ^{†1}. As a refinement of OPE calculations, form factors and short-range correlation effects must also be included but certainly will not alter much the preceding result.

However, in a preliminary stage it is interesting to analyze the presently available experimental data in terms of effective wave functions in the form (6). The procedure amounts merely to use muon capture with

^{†1} J. Delorme, private communication.

Table 2

Values of the $0^{-} \rightarrow 0^{+}$ β -decay rate of ^{16}N (120 keV) and of the $0^{+} \rightarrow 0^{-}$ μ -capture rate in ^{16}O (g.s.) for various configuration mixing coefficients X of the $(1p_{3/2}^{-1}, 1d_{3/2})$ component. The ratio of these two rates is also given. $\Lambda_{\beta}^{\text{I}}$ and Λ_{μ}^{I} are the partial rates evaluated in impulse approximation. Λ_{β} and Λ_{μ} are the partial rates evaluated with the exchange current. These rates are in s^{-1} .

X	-0.30	-0.20	-0.10	0	0.10	0.20	0.30
Λ_{β}	3.02	2.39	1.80	1.27	0.81	0.44	0.17
$\Lambda_{\beta}^{\text{I}}$	0.85	0.65	0.48	0.32	0.19	0.09	0.03
$\Lambda_{\beta}^{\text{I}}/\Lambda_{\beta}$	3.60	3.70	3.80	4.00	4.30	4.90	6.60
Λ_{μ}	10300	8100	6060	4220	2650	1390	500
Λ_{μ}^{I}	6740	5220	3830	2600	1570	770	230
$\Lambda_{\mu}^{\text{I}}/\Lambda_{\mu}$	1.50	1.50	1.60	1.60	1.70	1.80	2.20

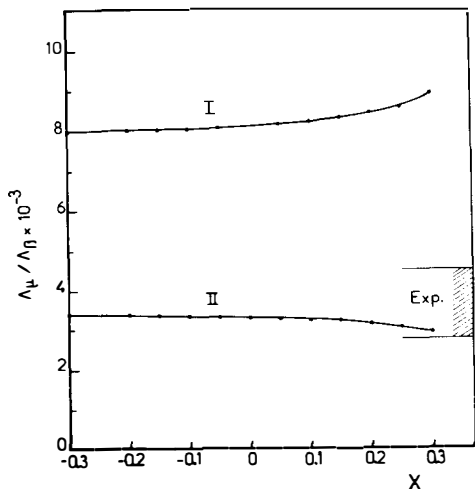


Fig. 1. Variation of the ratio $\Lambda_\mu(0^+ \rightarrow 0^-)/\Lambda_\beta(0^- \rightarrow 0^+)$ versus configuration mixing coefficient X for the $(1p_{3/2}^{-1}, 1d_{3/2})$ component. The curve I corresponds to the impulse approximation, the curve II includes the mesonic exchange correction. The experimental ratio (Exp.) was evaluated from the Saclay muon capture experiment [10] ($\Lambda_\mu(0^+ \rightarrow 0^-) = 1570 \pm 100 \text{ s}^{-1}$) and from the Louvain β -decay experiment [11] ($\Lambda_\beta(0^- \rightarrow 0^+) = 0.43 \pm 0.10 \text{ s}^{-1}$).

standard coupling constant to fix the value of X [9]. The rate of the reaction (2) is now well determined to be $\Lambda_\mu = 1570 \pm 100 \text{ s}^{-1}$ [10]. The same is not true for the process (1) since there is only one poor precision measurement $\Lambda_\beta = 0.43 \pm 0.10 \text{ s}^{-1}$ [11]. In fig. 1 we plot the ratio of μ -capture rate to β -decay rate with and without OPE correction as a function of X . Both ratios are nearly independent of X . Comparison with experimental data shows a surprising agreement for the OPE corrected ratio. Perhaps significant is the fact

that both β -decay and μ -capture experimental rates can be reproduced with a unique value of $X = 0.17$. (Let us emphasize that it is not at all the case for IA without allowing for a large enhancement of g_p [11]. This value which is large with respect to standard calculations of one particle–one hole wave functions is perhaps in favour of higher configuration mixtures.

These preliminary considerations are very encouraging for the possibility of detection of strong meson exchange effects in the axial current. Definitive answers must await both more precise measurement of the β -decay rate and theoretical effort to have more reliable estimations.

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