SEARCHING FOR PARITY NONCONSERVATION IN ^{10}B NUCLEUS

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The γ-circular polarization (P_γ) and asymmetries (A_γ) of the parity forbidden M1 + E2 γ-decays: $^{10}\mathrm{B}^*\,(J^\pi = 2^- T = 0; E_x = 5.11$ MeV) $\rightarrow$ $^{10}\mathrm{B}^*\,(J^\pi = 1^+ T = 0; E_x = 0.72$ MeV) as well as the PNC analyzing powers for resonance reaction populating the parity ($2^\pm$) doublet at 7.47 MeV have been investigated theoretically. We use the recently proposed Warburton–Brown shell model interaction. For the weak forces we discus comparatively different weak interaction models based on different assumptions for evaluating the weak meson–hadron coupling constants. The results determine a range of P_γ-values from which we find the most probable values: $P_\gamma = 3.7 \times 10^{-4}$ for the 5.11 MeV doublet and $A_{L(b)} \approx 0.6 \times 10^{-5}$ for the 7.47 MeV doublet. These cases seem to be promising for further experimental tests of parity nonconservation in nuclei.

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1. Introduction

Parity NonConservation (PNC) in the nucleon–nucleon (NN) interaction has been observed in the NN scattering induced by polarized projectiles (such as $\vec{p}$ [1, 2] or $\vec{n}$ [3]), in the spontaneous α-decay [4, 5] and in the circular polarization [6–8] or asymmetry [9–12] (from polarized nuclei) of the radiation emitted in nuclear γ-decay. There are also theoretical predictions for new PNC experiments in induced α-decay [13–18] and asymmetry of the radiation emitted in nuclear γ-decay [19, 20]. The theoretical and experimental work in this field was reviewed in papers [11, 12].

The controversy [11, 12, 21–23] in calculating weak meson–nucleon coupling constants in nuclei greatly stimulates the investigation of possible experiments sensitive to different components of the PNC interaction Hamiltonian ($H_{\rm PNC}$), that depend linearly on seven such weak coupling constants $\left(h_{\rm meson}^{(\Delta T)} : h_\pi^{(1)}, h_\rho^{(0)}, h_\rho^{(1)}, h_\rho^{(2)}, h_{\rho'}^{(1)}, h_\omega^{(0)}, h_\omega^{(1)}\right)$. Various linear combinations of these constants can, in principle, be extracted in different experiments, and among these are those for the parity mixed doublets (PMD) [11, 20]. Since the PMD has definite isospins, the transition "filters out" specific isospin components of PNC weak interaction.

In the excitation spectrum [24] of the ^{10}B nucleus there is [25, 26] one PMD ($\Delta E \approx 50$ keV) lying at 5.12 MeV excitation energy (see Table I). Different observable can give information on PNC in this doublet. Three of them have been found to provide a sizable enhancement of the effect. Two are the circular polarization of the 4.39 MeV and 5.11 MeV γ-rays from the $2^-; T = 1$ level to the first excited state ($1^+; T = 0$), for which Bizzeti and Perego [27] calculated the enhancement factors $f \cong 10$ and $f \cong 80$, respectively (see also Ref. [28]). The third one is the longitudinal analyzing power of the reaction $\alpha(^6\overrightarrow{\rm Li}, ^6{\rm Li})\alpha$ in which it is populated the PMD mentioned above [27], for which we calculated the big enhancement factor ($F \cong 4500$). The rough estimations of the circular polarization above mentioned, within PSDMK + DDH [12, 29] are 1.1×10^{-4} for 4.39 MeV γ-ray and 3.2×10^{-4} for 5.11 MeV γ-ray.

TABLE I

Different input data and physical quantities necessary for calculating γ-circular polarizations and analysing powers for the two PMD cases studied in the present work. The lifetimes for PMD1 levels are calculated using OXBASH code [29] and Warburton–Brown interaction [30].

PMD	PMD1	PMD2
$I_i^\pi T_i; E_i$ (MeV) $\to I_f^\pi T_f; E_f$ (MeV)	$2^+1; 5.1639$ MeV$\to 1^+0; 0.71832$ MeV	$2^-1; 7.478$ MeV
$I_i^\pi T_i; E_i$ (MeV) $\to I_f^\pi T_f; E_f$ (MeV)	$2^-0; 5.11003$ MeV$\to 1^+0; 0.71832$ MeV	$2^+0; 7.43$ MeV
Life time (τ^{2+})	$\cong 6$ fs	$\cong 0.6 \times 10^{-5}$ fs
Life time (τ^{2-})	$\cong 0.6 \times 10^{-3}$ fs	$\cong 0.8 \times 10^{-5}$ fs
f	100	$\cong 1$

There is a second PMD [24] of the ^{10}B nucleus ($\Delta E \approx 48$ keV) lying at 7.47 MeV excitation energy (see Table I). In addition to the γ-decay and the $\alpha(^6\overrightarrow{\rm Li}, ^6{\rm Li})\alpha$ reaction one can use a new channel namely, the $^9{\rm Be}\,(\vec{p}, \alpha)^6{\rm Li}$ resonance reaction. Thus, the PNC analyzing powers for $^9{\rm Be}\,(\vec{p}, \alpha)^6{\rm Li}$ resonance reaction populating the parity ($2^\pm$) doublet at 7.47 MeV have been investigated theoretically.

In the present paper a theoretical investigation of the two mentioned PMD cases is presented. The corresponding PNC — matrix elements were calculated within the shell model code — OXBASH, with the Warburton–Brown interaction [30] for $1s1p$–$2s1d$–$2p1f$ model space.

The aim of the present paper is to calculate the PNC-circular polarization of the gamma ray emitted in the parity forbidden M1 + E2 transition $^{10}\mathrm{B}^*\,(J^\pi\!=\!2^- T\!=\!0;\ E_x\!=\!5.11$ MeV$) \to {}^{10}\mathrm{B}^*\,(J^\pi\!=\!1^+ T\!=\!0;\ E_x\!=\!0.72$ MeV$)$ and the parity nonconserving analyzing powers $(A_L\,(b))$ for the $^9\mathrm{Be}\,(\vec{p},\alpha)^6\mathrm{Li}$ resonance reaction, populating the parity doublet at 7.47 MeV, within different interaction models, in order to judge the experiment feasibility.

Bearing in mind, that for PMD′s, the ratio $\frac{M_{\mathrm{PNC}}}{\Delta E}$ (and consequently the magnitude of the PNC pseudoscalar observable) is usually of the order 10^{-8} for $\Delta E \geq 1.0$ MeV, we may define a specific enhancement factor ($F = 10^8\,\frac{M_{\mathrm{PNC}}}{\Delta E}\,f$). f stands for the ratio of the decay (formation) amplitude corresponding to the unnatural parity level to that of the natural parity level [11]. The enhancement factors F for many cases of interest are summarized in Ref. [20].

2. Circular polarizations and analyzing powers

The PNC-γ asymmetry is given [31] by sum of parity nonconsering (PNC) and parity conserving (PC) contributions:

$$A_\gamma\,(\cos\theta) = (P_\gamma)_0 \times R_\gamma^{\mathrm{PNC}}\,(\cos\theta) + R_\gamma^{\mathrm{PC}}\,(\cos\theta)\ . \tag{1}$$

Here

$$(P_\gamma)_0 = 2\frac{|M_{\mathrm{PNC}}|}{\Delta E}\sqrt{\frac{b_+\tau_-}{b_-\tau_+}}\left(\frac{E_\gamma^-}{E_\gamma^+}\right)^{\frac{3}{2}} \tag{2}$$

and

$$(P_\gamma)_{\mathrm{un}} = (P_\gamma)_0\sqrt{\frac{1+\delta_-^2}{1+\delta_+^2}} \tag{3}$$

are the circular polarizations for unpolarized initial nucleus with zero and finite mixing $(\delta_\pm)$ and branching ratios $(b_\pm)$ [32], respectively, and

$$\begin{aligned} R_\gamma^{\mathrm{PNC}}\,(\cos\theta) &= \sqrt{\frac{1+\delta_-^2}{1+\delta_+^2}} \\ &\times\Big[\sum_{\nu=0,2,4} P_\nu\,(\cos\theta)\,B_\nu\,(2)\,(F_\nu\,(1112)+F_\nu\,(2212)\,\delta_+\delta_+ + F_\nu\,(1212)\,(\delta_- + \delta_+))\Big] \\ &\times\Big[\sum_{\nu=0,2,4} P_\nu\,(\cos\theta)\,B_\nu\,(2)\,F_\nu\,(1112) + F_\nu\,(2212)\,\delta_-^2 + 2F_\nu\,(1212)\,\delta_-\Big]^{-1} \end{aligned} \tag{4}$$

is a multiplier due to the existence of the orientation of the nucleus in the initial excited state when the mixing ratios do not vanish. The parity conserving (PC) γ-asymmetry is given by [31]:

$$\begin{aligned} & R_\gamma^{\mathrm{PC}}(\cos\theta) \\ & = \Big[\sum_{\nu=1,3} P_\nu(\cos\theta)\, B_\nu(2)\,(F_\nu(1112) + F_\nu(2212)\,\delta_-^2 + 2F_\nu(1212)\,\delta_-\Big] \\ & \times \Big[\sum_{\nu=0,2,4,} P_\nu(\cos\theta)\, B_\nu(2)\,\big(F_\nu(1112) + F_\nu(2212)\,\delta_-^2 + 2F_\nu(1212)\,\delta_-\big)\Big]^{-1}, \quad (5) \end{aligned}$$

where

$$B_\nu(2) = \sum_M (2\nu+1)^{\frac{1}{2}}\, C(2\nu 2; M0M)\, p(M) \qquad (6)$$

in which $p(M)$ is the polarization fraction of the M-state, which determines the degree of the orientation of the nucleus and

$$\begin{aligned} F_\nu\left(LL'I'I\right) &= (-1)^{I'+3I-1}\left[(2I+1)(2L+1)\left(2L'+1\right)\right]^{\frac{1}{2}} \\ & \quad \times C\left(LL'\nu; 1-10\right) W\left(LL'II; \nu I'\right). \qquad (7) \end{aligned}$$

In order to measure a PNC effect one must find situations for which the R_γ^{PC} part in Eq. (1) vanishes. Two particular cases have this property:

(i) the case of an initially unpolarized nucleus for which $B_0(2) = 1$, $B_{\nu\neq 0}(2) = 0$ and $F_0\left(LL'22\right) = \delta_{LL'}$. In this particularly simple case P_γ reduces to the well known expression of the circular polarization, $(P_\gamma)_{\mathrm{un}}$;

(ii) one may prepare a polarized state by choosing $p(M) = \delta_{M0}$ for which, $B_{\nu=1,3}(2) = 0$ and R_γ^{PC} part vanishes. The foregoing expression for gamma asymmetry (A_γ) then reduces to well-known expression of the circular polarization, $A_\gamma = (P_\gamma)_{\mathrm{un}}$.

The largest energy anomalies of the PNC A_L (longitudinal) and A_b (irregular transverse) analyzing powers for the $^9\mathrm{Be}(\vec{p},\alpha)^6\mathrm{Li}$ resonance reaction populating the ($2^\pm$) PMD at 7.47 MeV excitation energy are around the energy of the small width level of the PMD. They have the following simple expression [16, 17]:

$$A_L(b) = D_L(b)\,\frac{1}{2}\Gamma^{\mathrm{small}}\left(E - E^{\mathrm{small}} + \frac{i}{2}\Gamma^{\mathrm{small}}\right)^{-1} \mathrm{e}^{i\left(\phi_{\mathrm{PC}}^{\mathrm{L}(b)} + \phi_{\mathrm{PNC}}\right)}, \qquad (8)$$

where

$$D_L\left(b\right)=\frac{\left|M_{\rm PNC}\right|}{\left|\left(E-E^{\rm large}+\frac{i}{2}\Gamma^{\rm large}\right)\right|}\sqrt{\frac{\Gamma^{\rm large}}{\Gamma^{\rm small}}}\mid C_L\left(b\right)\mid \tag{9}$$

in which

$$C_L\left(b\right)=\left|C_L\left(b\right)\right|{\rm e}^{i\phi_{\rm PC}^{L(b)}}=2\frac{\left|\left(E-E^{\rm large}+\frac{i}{2}\Gamma^{\rm large}\right)\right|}{\sqrt{\Gamma^{\rm large}\Gamma^{\rm small}}}$$
$$\times\frac{\sum_l P_l^{(k)}\left(\cos\theta\right)\left[\sum_n c_n^l\left(L\left(b\right)\right)iC\left(\theta\right)\delta_{\beta,\beta_1}\tilde{t}_n^*+\sum_{mn}b_{mn}^l\left(L\left(b\right)\right)\left(\tilde{t}_m t_n^*+\tilde{t}_m^* t_n\right)\right]}{\sum_l P_l\left(\cos\theta\right)\sum_{mn}a_{mn}^l t_m t_n^*} \tag{10}$$

is a function on the PC transition matrix ($T^{I^\pi}_{\beta ls,\beta' l' s'}=t_n$) elements only (for L: k =0, for b: $k=1$, $\tilde{t}_n=T^{\rm large}_{pls,pl_1s_1}\exp\left[i\left(\xi_{pls}-\xi_{pl's'}\right)\right]$. The coefficients $a_{mn}^{(l)}\left(L\left(b\right)\right)$, $b_{mn}^{(l)}\left(L\left(b\right)\right)$ and $c_n^{(l)}\left(L\left(b\right)\right)$ are simple specific values of the geometrical coefficients for the case we are investigating now. The superscripts "large" and "small" correspond to the quantities of the PMD levels with large, respectively, small widths. In the factor $D_L\left(b\right)$ we separated the enhancement factor $F(D_L\left(b\right)=10^{-8}\,F\left|C_L\left(b\right)\right|)$, which always estimates the magnitude of the PNC analyzing powers, the quantity $C_L\left(b\right)$ being very close to the unity in many cases when coherence effects arise. In the case of random phases, in the numerator of $C_L\left(b\right)$, this factor acts destructively and in any case it should not be omitted. To calculate this last factor is the most complicated part of the PNC calculation investigated via resonance reaction processes. In this case we have to deal with 9 PC T-matrix elements and 12 PNC T-matrix elements in the case we cut at $l=2$ and $I=2$, however there are many more T-matrix elements with $l=2$ and $I\geq 2$. In the Refs. [16, 17] only 4 PC T-matrix elements and 2 PNC T-matrix elements have been examined. In that case, the α-channel phases have been extracted from the experiment, the two PNC T-matrix elements being equal. Unfortunately, in this case, the only performed experiment [33] did not study the energy region of our interest. A theoretical investigation of $C_L\left(b\right)$ will be reported in a future paper. In this letter we shall assume $\left|C_L\left(b\right)\right|\approx 1$.

3. PNC matrix elements

In order to determine the magnitude of the PNC observables (P_γ and $A_L\left(b\right)$) we have made a shell model estimate of the PNC matrix element,

$$M_{\rm PNC}=\left\langle J^\pi T,E_x\left({\rm MeV}\right)\middle|H_{\rm PNC}\middle|J^{-\pi}T',E_x'\left({\rm MeV}\right)\right\rangle=\sum_{k,s}F_{k,s}M_{k,s}\,, \tag{11}$$

where $H_{\rm PNC}$ is the parity nonconserving Hamiltonian for nuclear interactions, $F_{k,s}$ are coefficients depending by the weak ($h^{(\Delta T)}_{\rm meson}$) and strong ($g_{\rm meson}$) coupling constants and $M_{k,s}$ are nuclear structure matrix elements:

$$M_{k,s} = \left\langle J^{\pi} T, E_x\,({\rm MeV}) \left| f_{k,s} \right| J^{-\pi} T', E'_x\,({\rm MeV}) \right\rangle. \tag{12}$$

The $F_{k,s}$ coefficients are calculated using Kaiser & Meissner (KM) [21], Desplanques, Donoghue & Holstein (DDH) [12], Adelberger & Haxton (AH) [11] and Dubovik & Zenkin (DZ) [22] models for PNC hadronic interactions. Details about these models can also be found in Ref. [34]. The operators $f_{k,s}$ are defined by Eqs. (10)–(19) from Ref. [35].

The $M_{k,s}$ matrix elements calculations were carried out with the shell-model code OXBASH [29] in the $1s1p$-$2s1d$-$2p1f$ model space in which the $1s_{1/2}$, $1p_{3/2}$, $1p_{1/2}$, $2s_{1/2}$, $1d_{5/2}$, $1d_{3/2}$, $2p_{1/2}$, $2p_{3/2}$, $1f_{7/2}$ and $1f_{5/2}$ orbitals are active. The Warburton–Brown interaction [30] was used and a $0\hbar\omega$-truncation for the positive parity states and a $1\hbar\omega$-truncation for the negative parity states were necessary to be done due to the dimension limitations, but we believe that they are realistic, because the used interaction have been tested extensively with regards to the reproduction of spectroscopic properties [30].

All the components [11, 12] of the parity nonconserving potential are short range two-body operators. Because the behavior of the shell model wave functions at small NN distances has to be modified, short range correlations (SRC) were included by multiplying the harmonic oscillator wave functions (with $\hbar\omega = 25A^{-\frac{1}{3}}$ MeV $\div$ $45A^{-\frac{1}{3}}$ MeV) by the Miller and Spencer factor [36]:

$$1 - \exp(-ar^2)(1 - br^2); \quad a = 1.1\,{\rm fm}^{-2}; \quad b = 0.68\,{\rm fm}^{-2}.$$

This procedure is consistent with the results obtained by using more elaborate treatments of SRC such as the generalized Bethe–Golstone approach [7], of the matrix elements without including SRC, while the $\rho\,(\omega)$ exchange matrix elements is much smaller (by a factor of $\frac{1}{3} \div \frac{1}{6}$). The one-body contributions, generally, are larger then two-body ones by a factor of $\cong 2 \div 7$ (and sometimes they come with opposite signs in the ^{36}Cl case). In the ^{36}Ar case the one-body PNC matrix elements are negligible small as compared to the two-body ones.

4. Numerical results

Using the weak coupling constants [11,12,21,22] given in Table II, we first calculated the $F_{k,s}$ coefficients (Table III). The strong coupling constants

TABLE II

Weak meson–nucleons coupling constants (in units of 10^{-7}) calculated within different weak interaction models. The abbreviations are: KM = Kaiser and Meissner [21], DDH = Desplanques, Donoghue and Holstein [12], AH = Adelberger and Haxton [11] and DZ = Dubovik and Zenkin [22].

$h^{\Delta T}_{\rm meson}$	KM	DDH	AH	DZ
h^1_π	0.19	4.54	2.09	1.30
h^0_ρ	−3.70	−11.40	−5.77	−8.30
h^1_ρ	−0.10	−0.19	−0.22	0.39
h^2_ρ	−3.30	−9.50	−7.06	−6.70
$h^1_{\rho'}$	−2.20	0.00	0.00	0.00
h^0_ω	−1.40	−1.90	−4.97	−3.90
h^1_ω	−1.00	−1.10	−2.39	−2.20

TABLE III

The expressions of the coefficients $F_{k,s}$ multiplying matrix elements $M_{k,s}$ are given in the first column. Numerical values (in units of 10^{-6}) are given within KM, DDH, AH and DZ models for PNC nucleon–nucleon interaction.

$F_{k,s}$	KM	DDH	AH(fit)	DZ
$F_{0,\pi} = \frac{1}{2\sqrt{2}} g_\pi h^1_\pi$	0.090	2.16	0.995	0.617
$F_{1,\rho} = -\frac{1}{2} g_\rho h^1_\rho$	0.014	0.027	0.805	−0.544
$F_{2,\rho} = -\frac{1}{2} g_\rho h^1_\rho (1+\mu_v)$	0.066	0.127	0.144	−0.256
$F_{3,\rho} = \frac{1}{2} g_\rho h^1_\rho$	−0.014	−0.027	−0.031	0.054
$F_{1,\omega} = -\frac{1}{2} g_\omega h^1_\omega$	0.437	0.480	1.000	0.921
$F_{2,\omega} = -\frac{1}{2} g_\omega h^1_\omega (1+\mu_s)$	0.384	0.423	0.880	0.810
$F_{3,\omega} = -\frac{1}{2} g_\omega h^1_\omega$	0.437	0.480	1.000	0.921
$F_{4,\rho} = -g_\rho h^0_\rho (1+\mu_v)$	4.850	14.94	7.566	10.884
$F_{5,\rho} = -g_\rho h^0_\rho$	1.032	3.180	1.610	2.316
$F_{6,\omega} = -g_\omega h^0_\omega (1+\mu_s)$	1.038	1.408	3.661	2.872
$F_{7,\omega} = -g_\omega h^0_\omega$	1.179	1.600	4.160	3.264
$F_{0,\rho} = -\frac{1}{2} g_\rho h^1_{\rho'}$	0.307	0.00	0.00	0.00
$F_{8,\rho} = -\frac{1}{2\sqrt{2}} g_\rho h^2_\rho (1+\mu_v)$	0.886	2.542	1.888	1.792
$F_{9,\rho} = -\frac{1}{2\sqrt{6}} g_\rho h^2_\rho$	0.189	0.541	0.402	0.381

are [11]: $g_\pi = 13.45, g_\rho = 2.79$ and $g_\omega = 8.37$. The magnetic moments are $\mu_\nu = 3.7$ and $\mu_s = -0.12$. The final results for parity non-conserving matrix elements ($M_{\rm PNC}$) are tabulated (Table IV). This last step is a very important one because all PNC observables depend on $M_{\rm PNC}$. A good estimation of these matrix elements together with a carefully calculation of the P_γ and $A_L\,(b)$ for a given PMD can lead us to valuable predictions. Unfortunately, this kind of calculation is affected by major uncertainties. However, using the formalism briefly described in section 2, we can derive the mean values of the PNC observables. These values, calculated within different models of weak interaction [11, 12, 21, 22] are given in Table V.

TABLE IV

Parity non-conserving matrix elements values (in eV) calculated in different PNC interactions using shell-models code OXBASH [29] in the $1s1p$–$2s1d$–$2p1f$ model space with Wartburton–Brown interaction [30] and short range correlations (SRC).

$M_{\rm PNC}$ (PMD)	KM	DDH	AH	DZ	Average value
$M_{\rm PNC}$ (PMD1)	−0.014	−0.211	−0.106	−0.080	−0.100
$M_{\rm PNC}$ (PMD2)	−0.046	−0.815	−0.310	−0.230	−0.350

TABLE V

The mean values (in units of 10^{-5}) of the PNC observables: circular polarization (P_γ) and analyzing powers ($A_L\,(b)$) calculated using matrix elements values given in Table IV.

Interactions	P_γ (PMD1)	$A_L\,(b)$(PMD2)
KM	5	0.1
DDH	78	1.7
AH	39	0.6
DZ	30	0.5

Let us discuss a little more these results. Because of the significant differences between weak interaction models (see Table II), the PNC matrix elements values differ by a factor of 15 for PMD 1 and approx. 18 for PMD 2; this fact is reflected in the final results for PNC observable values. The average values ($\overline{M}_{\rm PNC}$ (PMD1) = −0.1 eV and $\overline{M}_{\rm PNC}$ (PMD2) = −0.35 eV) are very close to the Adelberger & Haxton (AH) values. On the other hand, excluding the KM values (too small) and DDH values (in our opinion, too large) we need to choose between AH and DZ values (that do not differ so much). The AH values are found from fitting the experimental data, while the DZ values are obtained using quark plus Weinberg–Salam model for elementary strong and weak interactions between nucleon's constituents. In this context we conclude that for the PNC matrix elements we can choose, as "realistic" values, the following specific numbers: $M_{\rm PNC}^{\rm PMD1} = -0.1$ eV and

$M_{\rm PNC}^{\rm PMD2} = -0.3$ eV. Using these last quantities, the most probable values for PNC observables are: $P_\gamma^{\rm PMD1} = 3.7 \times 10^{-4}$ and $A_L\,(b)^{\rm PMD2} = 0.6 \times 10^{-5}$ (Table VI).

TABLE VI

Experimental and theoretical values (in units of 10^{-5}) of PNC observables for some nuclei.

Observable	Exp. Value	Theor. Value	References
$A_{\rm L}^{\rm PMD1}\left(^{14}{\rm N}\right)$	0.86 ± 0.59	3.1	[11,36]
$A_{\rm L}^{\rm PMD2}\left(^{14}{\rm N}\right)$	—	1	[37]
$A_{\rm L}^{\rm PMD1}\left(^{16}{\rm O}\right)$	—	1.4	[17]
$A_{\rm L}^{\rm PMD2}\left(^{16}{\rm O}\right)$	—	3.2	[38]
$P_\gamma^{\rm PMD1}\left(^{18}{\rm F}\right)$	8 ± 39	208	[11]
$A_\gamma^{\rm PMD1}\left(^{19}{\rm F}\right)$	-7.4 ± 1.9	8.9	[9,11]
$P_\gamma\left(^{21}{\rm Ne}\right)$	80 ± 140	46	[11,39]
$P_\gamma\left(^{23}{\rm Na}\right)$	—	6	[20]
$P_\gamma\left(^{30}{\rm P}\right)$	—	70	[20]
$P_\gamma^{\rm PMD1}\left(^{36}{\rm Cl}\right)$	—	13	[19]
$P_\gamma^{\rm PMD1}\left(^{10}{\rm B}\right)$	—	37	present work
$A_L\,(b)^{\rm PMD2}\left(^{10}{\rm B}\right)$	—	$\cong 0.6$	present work

5. Conclusions

The calculation of the PNC effects in the nuclei is usually divided in four parts:

(I) the weak ($h_{\rm meson}^{(\Delta T)}$) and strong ($g_{\rm meson}$) coupling constants are calculated starting from the quark structure of the nucleons and their elementary interactions [12, 22], by applying effective theories of mesons and baryons [21] or by fitting of experimental data [11];

(II) the PNC interaction Hamiltonian ($H_{\rm PNC}$) is derived in terms of coupling constants previously calculated [11];

(III) the PNC matrix elements ($M_{\rm PNC}$) of $H_{\rm PNC}$ between nuclear wave functions are computed using an appropriate software (like OXBASH code [29]);

(IV) PNC observables are predicted in terms of $M_{\rm PNC}$.

The first two parts belong to the elementary particle physics, while the last two need nuclear matter techniques.

The goal of the present paper is to calculate the circular polarization (P_γ) of the 4.39 MeV γ-rays emitted in the transition $^{10}\mathrm{B}^*\,(2^-0; 5.11003$ MeV$)$ $\rightarrow$ $^{10}\mathrm{B}^*\,(1^+0; 0.71832$ MeV$)$ (see Table I) and the PNC analyzing powers ($A_L\,(b)$) for the $^9\mathrm{Be}(\vec{p},\alpha)^6\mathrm{Li}$ resonance reaction populating the parity ($2^\pm$) doublet at 7.47 MeV. In order to do this, we used the formalism developed in Refs. [7, 8, 11, 12, 19, 20] briefly reviewed in Section 2, and also the four PNC Hamiltonians (KM [21], DDH [12], AH [11] and DZ [22]) that enter as input data in Section 4. The results are (Table V) $P_\gamma = (0.5 \div 7.8) \times 10^{-4}$ and $A_L\,(b) \approx (0.1 \div 1.7) \times 10^{-5}$. The most probable values ($P_\gamma = 3.7 \times 10^{-4}$ and $A_L\,(b) \approx 0.6 \times 10^{-5}$) are in agreement with other experimental and theoretical results (Table VI) that encourages us to propose these cases for experiment.

The parity mixing between the members of the above mentioned doublets is of particular interest because:

(1) The mixing is sensitive to the $\Delta T = 1$ components of H_{PNC}. In this case we might have quantitative information about neutral currents contributions to H_{PNC}. There are very few experiments sensitive only to the $\Delta T = 1$ PNC nucleon–nucleon amplitudes. One of these is ^{18}F experiment (see Table VI and reference therein). Our result for circular polarization is larger then experimental value and smaller than theoretical expectation value for ^{18}F case. The large difference between theoretical and experimental values remains to be explained in the future.

(2) The two observables analyzed here provide a precise way to measure the PNC matrix elements. The small level spacing between the states of the parity mixed doublets (PMD's) and the different decay (formation) amplitudes (especially for PMD1) lead to a considerable enhancement of the PNC effect. Usually such enhancements are offset due to correspondingly large theoretical uncertainties in the extraction of the PNC parameters from the experimental data. As a matter of fact, the same conditions which generate the enhancement, complicate a reliable theoretical determination of the nuclear matrix elements. Therefore, it is necessary to select exceptional cases, in which the nuclear structure problem can be solved. The parity mixed doublets in ^{10}B are, in our opinion, appropriate for theoretical and experimental investigations.

(3) The theoretical models included in the OXBASH code are reasonably good at least for the levels included in the two PMD's.

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