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ON PARITY-VIOLATION EFFECTS IN NUCLEON-ANTINUCLEON INTERACTIONS AT LOW ENERGIES

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§1. INTRODUCTION

The description of weak nucleon-nucleon interaction is one of the most difficult fields of application of the standard electroweak model (SEWM) (see, e.g., review [1]). The matter is that the SEWM has been formulated in terms of quarks, while the dynamical models of strong interactions which allow the transition to the language of mesons and nucleons are not complete. For instance, we cannot yet obtain the nuclear potentials from QCD and in practice have not studied their behaviour at distances $r \lesssim 0.5$ fm, critical for weak interactions. Therefore, the description of parity violation (PV) in the hadron reactions is semiphenomenological.

There are two approaches to the description of the PV effects in the nucleon systems: potential [2,3] and quark-nuclear [4] approaches. The potential approach allows for weak corrections into the vertices of diagrams of the one-meson exchange between nucleons. Note that one-pion exchange effectively occurring at internucleon distances $r \sim 1.4$ fm is responsible for the long-range, well-studied, part of the nuclear forces, and the method of the potential description of both strong and weak interactions is rather reliable in this region. The exchange by vector ρ and ω mesons is effective in the range $r \sim 0.25$ fm, where the nuclear potentials cannot be reconstructed uniquely from the experimental data on NN scattering because at these distances two nucleons are not representable as two elementary point-like particles. In this range, besides the potential contribution, it is necessary to take into account the quark-nuclear contribution, i.e., the contribution of the weak interaction, which arises by central nucleon collisions with forming of 6q -states (of fluctuons or their resonance parts - dibaryons). Apparently, it is the reason the potential calculations of the PV effects at the reactions, where ρ,ω exchanges only are allowed, clarify a small parts of measured magnitudes: $\sim 0.01 P_{\gamma}$ - the circular polarization of γ-quanta in $np \to d\gamma$ [5] and $\sim 0.1 A_{pp}$ - the asymmetry in $\vec{p}p \to pp$ [6].

So, there is the problem of separation of the potential contribution to the PV effects from the quark-nuclear one and individual determination of the six constants of the weak

$\tilde{N}N$ potential. In this situation of great importance are the data on PV in the simplest reactions and systems.

In the last years, among the simplest hadron systems there are widely discussed the quasinuclear $\tilde{N}N$ systems predicted by theoretical calculations [7,8]. There search is being in progress in many experiments (see, e.g., review [9]). Certain interest represents the study of the PV effects in elastic $\tilde{p}p \to \tilde{p}p$ scattering, in annihilation processes of $\tilde{N}N$ system, and in γ-transitions in the quasinuclear systems.

The quasinuclear system is less loose than the deuteron since in the language of OBEP the attraction is performed by the ω meson and $g_\omega > g_\rho$; its radius $R_{\tilde{N}N} \lesssim 1$ fm. The latter, together with other properties of the system gives rise to interesting specific features of the PV in γ-transitions in $\tilde{N}N$. Recall that the system $\tilde{N}N$ instantly annihilates if its quarks and antiquarks fluctuate into a small volume $r \ll R_{\tilde{N}N}$ because the annihilation cross section is very large and annihilation radius is $R_A \simeq \frac{1}{2M_N} \simeq 0.1 \div 0.2$ fm. Then it follows that at small r the wave function of the system vanishes and the quark-nuclear effects in it (in baryonium) cannot be so large as in the deuteron [4] (in dibaryon $R_{NN} \simeq 0.3 \div 0.4$ fm). On the contrary, the potential contributions into PV in the quasinuclear systems will increase because baryonium is a more compact system ($R_{\tilde{N}N} < R_d$). Further, owing to the abundance of levels in the deep $\tilde{N}N$ potential [7,8] one can select several interesting transitions for the study of the PV effects. Along this way, since the spin-isospin structure of the weak vector potential in the $\tilde{N}N$ system (§2) differs considerably from the potential structure in NN, there appears, in principle, a possibility of the measurements of other set of constants of the Hamiltonian of weak NN interactions. And finally, in view of the compactness of the $\tilde{N}N$ system in electric E1-transition contribution by the toroidal dipole [10] are important (§3); its role in the problem on PV was discussed earlier in our paper [11]. Results of calculations and discussions are presented in §4. Appendix gives the form of PV potentials in the NN and $\tilde{N}N$ systems.

§2. PARITY-VIOLATING $\tilde{N}N$ POTENTIAL

To construct the $\tilde{N}N$ potential, we proceed from a known expression for the NN potential [1,2]. The effective Hamiltonian of $NNM (M = \pi, \rho, \omega)$ interaction taking into account PV has the form *

$$\mathcal{H} = \mathcal{H}^{P.C.} + \mathcal{H}^{P.V.}, \tag{1}$$

$$\mathcal{H}^{P.C.} = ig_\pi \bar{N}\gamma_5 \vec{\tau}\vec{\pi} N + g_\rho \bar{N}[i\gamma_\mu \vec{\rho}_\mu + (\mu_V - 1)\frac{\sigma_{\mu\nu}}{2M_N}\partial_\mu \vec{\rho}_\nu]\frac{1}{2}\vec{\tau}N + \tag{2}$$

$$+ g_\omega \bar{N}[i\gamma_\mu \omega_\mu + (\mu_S - 1)\frac{\sigma_{\mu\nu}}{2M_N}\partial_\mu \omega_\nu]\frac{1}{2}\tau^\circ N,$$

$$\mathcal{H}^{P.V.} = G_\pi \bar{N}(\vec{\tau}\times\vec{\pi})^3 N + iG_V \bar{N}\gamma_\mu\gamma_5[\sqrt{2}a(\tau^+\rho_\mu^- + \tau^-\rho_\mu^+) + \tag{3}$$

$$+ \frac{1}{2}(b\tau^3 + \zeta c\tau^\circ)\rho_\mu^\circ + \frac{1}{2}(c'\tau^3 + \zeta d\tau^\circ)\omega_\mu]N.$$

Here $\sigma_{\mu\nu} = \frac{1}{2i}[\gamma_\mu, \gamma_\nu]$, $N = \binom{p}{n}$, $\tau^\pm = \frac{1}{2}(\tau^1 \pm i\tau^2)$, $\tau^\circ = 1$, $\mu_V = \mu_p - \mu_n$ ($\mu_S = \mu_p + \mu_n$) is the isovector (isoscalar) magnetic moment of nucleons, $g_\omega = 3g_\rho$, $G_\pi = \frac{G_F}{\sqrt{2}} m_\pi^2 A_\pi$, $G_V = \frac{G_F g_A m_\rho^2}{\sqrt{2}\, g_\rho}$, $\zeta = \frac{3F - D}{F + D}$, and six constants A_π, a, b, c, c', d determine the PV NNM interaction.

The PV NN interaction is described by diagrams of Fig.1 which in the nonrelativistic limit, define the PV NN potential:

$$V = V^\pi + V^\rho + V^\omega, \tag{4}$$

$$V^M = V_{12}^M + V_{21}^M, \tag{5}$$

$$V_{ij}^\pi = i\frac{G_\pi g_\pi}{2M_N}\vec{\sigma}_i[\vec{p}_i, f_\pi](\vec{\tau}_i \times \vec{\tau}_j)^3, \tag{6}$$

$$V_{ij}^V = -\frac{G_V g_V}{2M_N}(\vec{\sigma}_i\{\vec{p}_i - \vec{p}_j, f_V\}I_{ij}^V - i(\vec{\sigma}_i \times \vec{\sigma}_j)[\vec{p}_j, f_V]T_{ij}^V), \quad V = \rho, \omega, \tag{7}$$

$$I_{ij}^\rho = a(\tau_i^+\tau_j^- + \tau_i^-\tau_j^+) + \frac{1}{4}(b\tau_i^3\tau_j^3 + \zeta c\tau_i^\circ\tau_j^3), \tag{8}$$

$$I_{ij}^\omega = \frac{1}{4}(c'\tau_i^3\tau_j^\circ + \zeta d\tau_i^\circ\tau_j^\circ), \tag{9}$$

$$T_{ij}^\rho = \mu_V I_{ij}^\rho, \quad T_{ij}^\omega = \mu_S I_{ij}^\omega, \quad f_M = \frac{e^{-m_M r}}{4\pi r}, \tag{10}$$

$$r = |\vec{x}_1 - \vec{x}_2|, \quad i,j = 1,2.$$

* We use the Pauli metrics.

The potential V_{12} corresponds to diagram (a); V_{21} to diagram (b) of Fig.1. That it is necessary to allow for all the eight diagrams of Fig.1 is caused by antisymmetry of the wave functions of the NN initial and final states.

Now let us construct the $\tilde{N}N$ potential.

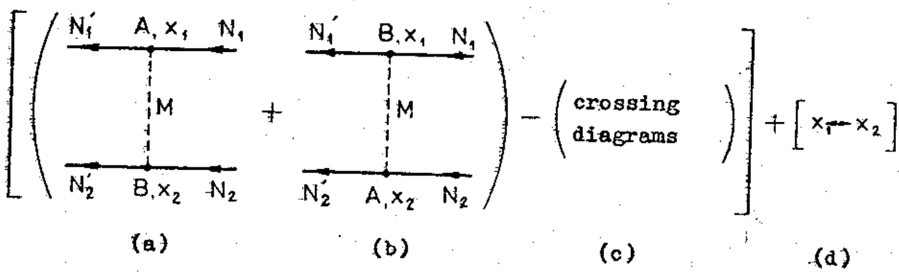

Fig.1. The parity-violating vertices A are defined by the Hamiltonian $\mathcal{H}^{P.V.}$; the parity-conserving vertices B, by the Hamiltonian $\mathcal{H}^{P.C.}$

Transition from particles to antiparticles is performed through the G-transformation, i.e., doublet of antiparticles $\tilde{N} = G\bar{N}^T = G\gamma_4 N^*$, where $G = i\gamma_2\gamma_4\tau^2$. Let an antiparticle has a coordinate x_1. In this case the PV $\tilde{N}N$ interactions are described by diagrams following from diagrams of Fig.1 (denote them $(\tilde{a})$, $(\tilde{b})$, $(\tilde{c})$ and $(\tilde{d})$, resp.) via the change of currents $J(x_1)$ by G-conjugated currents $\tilde{J}(x_1) = GJ(x_1)G^{-1}$. Then the crossing diagrams turn into the annihilation diagrams and the exchange PV $\tilde{N}N$ potential is given by the diagrams $(\tilde{a})$ and $(\tilde{b})$*. Since all currents in the Hamiltonian $\mathcal{H}$ have definite G-parities, the only potential change in transition to the $\tilde{N}N$ system is the change of signs of constants entering into the G-odd currents. However, since in general the G-parities of currents in the Hamiltonian $\mathcal{H}^{P.V.}$ are different from those in the $\mathcal{H}^{P.C.}$, the potentials V_{12} and V_{21} will change in a different manner (see Table 1).

As a result, while passing to the $\tilde{N}N$ system the V^{π} merely changes sign and the potentials V^{V} change spin-isospin structure. For instance, the asymmetry of elastic $\tilde{p}p$ scattering at

* Diagrams $(\tilde{d})$ can be transformed into $(\tilde{a})$ and $(\tilde{b})$.

Table 1

The change of sign of the constants in the PV potential.

	g_π	G_π	g_ρ	$G_V a$	$G_V b$	$G_V c$	g_ω	$G_V c'$	$G_V d$
V_{12}	+	−	+	−	−	+	+	−	+
V_{21}	−	+	+	+	+	+	−	+	+

low energies (dozens of MeV) is defined by the PV transition $^3S_1 \to {}^3P_1$; while for pp scattering, by the transition $^1S_0 \to {}^3P_0$. Other nontrivial consequences of a change of this type will be considered in §3. The general form of the PV NN and $\tilde{N}N$ potentials is given in Appendix.

§3. OPERATORS OF ELECTROMAGNETIC TRANSITIONS AND SELECTION RULES FOR P_γ

The PV effects in quasinuclear systems may appear (like in nuclei) as the circular polarization of the emitted γ-quantum P_γ or emission asymmetry A_γ. These effects result from the admixture to the functions of initial (ψ_i) and final (ψ_f) states of the functions of all the system states with the same total moments but with different parities. As a rule, the estimation of the effect can be limited to the admixture of the nearest in energy level $\psi^{-\pi}$:

$$\bar{\psi}_{i,f} = \psi^{\pi}_{i,f} + \mathcal{F}\,\psi^{-\pi}_{i,f}, \qquad \mathcal{F} \sim 10^{-6} \div 10^{-7} \quad . \tag{11}$$

The PV effect is defined by interference of the regular (allowed) and irregular multipole amplitudes $EL\cdot\overline{ML}$ or $ML\cdot\overline{EL}$. For instance, P_γ equals:

$$P_\gamma = \frac{d\sigma^{(+)} - d\sigma^{(-)}}{d\sigma^{(+)} + d\sigma^{(-)}} \sim \frac{2EL\cdot\overline{ML}}{(EL)^2 + (\overline{ML})^2} \quad \text{or} \quad \frac{2ML\cdot\overline{EL}}{(ML)^2 + (\overline{EL})^2} . \tag{12}$$

Here $d\sigma^{(\lambda)}$ is the differential cross section of the emission of γ-quantum with given helicity λ:

$$d\sigma^{(\lambda)} = \frac{1}{2J_i + 1} \sum_{M_i, M_f} |\langle \psi_f^{M_f} | H_{em}(\lambda) | \psi_i^{M_i} \rangle|^2 \quad . \tag{13}$$

The electromagnetic radiation of a composite system is defined by the operator ($\hbar = c = 1$)

$$H_{em}(\lambda) = -\left(\frac{2\pi}{\omega}\right)^{1/2}\sum_{\ell}\left[\frac{e_\ell}{m_\ell}\vec{p}_\ell\,\vec{\epsilon}^{\,*}_\lambda - i\vec{\mu}_\ell\,(\vec{k}\times\vec{\epsilon}^{\,*}_\lambda)\right]e^{-i(\vec{k}\vec{r}-\omega t)} \quad , \tag{14}$$

where ω is the energy, $\vec{k}$, the momentum, $\vec{\epsilon}_\lambda$, the polarization of γ-quanta; e_ℓ, the charge, $\vec{\mu}_\ell$, the magnetic moment operator, $\vec{p}_\ell$, the momentum, m_ℓ, the mass of an ℓ-th particle of the system.

In long-wave approximation, in which terms including $(\vec{k}\vec{r})^2$ are retained, the dipole radiation is determined by the three dipole moments

$$H_{em}(\lambda) = \left(\frac{2\pi}{\omega}\right)^{1/2}\left[(\dot{\vec{Q}}_1 + \omega^2\vec{T}_1)\,\vec{\epsilon}^{\,*}_\lambda + i\vec{M}_1(\vec{k}\times\vec{\epsilon}^{\,*}_\lambda)\right] . \tag{15}$$

The first two moments compose the operator of the transverse electric transition $\vec{E}_1 = \frac{\partial}{\partial t}\vec{Q}_1 + \omega^2\vec{T}_1$. First of them for the case, when forces in the system do not depend on velocity, is proportional to the usual Coulomb dipole $\sum_\ell e_\ell\,\vec{r}_\ell$ (the Siegert theorem), and second, toroidal dipole moment /10/ takes account of all terms of the order $(\vec{k}\vec{r})^2$, which contribute to the E1-transition (compare, e.g., ref. /12/).

For the system of two particles of equal masses, e.g., NN or $\tilde{N}$N the operators $\dot{\vec{Q}}_1$, $\vec{T}_1$ and $\vec{M}_1$ in c.m.s. are written as follows

$$\dot{\vec{Q}}_1 = -\frac{1}{M_N}(e_1 - e_2)\,\vec{p} . \tag{16}$$

$$\vec{T} = \frac{1}{10M_N}(e_1 - e_2)\,\frac{\vec{r}^{\,2}}{4}\,\vec{p} - \mu_0\frac{1}{4}\vec{r}\times\left[\frac{\mu_1-\mu_2}{2}(\vec{\sigma}_1+\vec{\sigma}_2) + \right. \tag{17}$$

$$\left. + \frac{\mu_1+\mu_2}{2}(\vec{\sigma}_1-\vec{\sigma}_2) + \frac{2}{5}\,\frac{g_1-g_2}{2}(\vec{\ell}_1+\vec{\ell}_2)\right],$$

$$\vec{M}_1 = \mu_0\left[\frac{\mu_1+\mu_2}{2}(\vec{\sigma}_1+\vec{\sigma}_2) + \frac{\mu_1-\mu_2}{2}(\vec{\sigma}_1-\vec{\sigma}_2) + \frac{g_1+g_2}{2}(\vec{\ell}_1+\vec{\ell}_2)\right]. \tag{18}$$

Here $\vec{r} = \vec{r}_1 - \vec{r}_2$, $\vec{p} = \frac{\vec{p}_1-\vec{p}_2}{2}$, $\mu_0 = \frac{e}{2M_N}$, e is the proton charge. The formulas for charges and magnetic moments of N and $\tilde{N}$ are collected in Table 2.

Now let us obtain the selection rules for P_γ. Consider the case when P_γ results from the admixture of ψ_i' to ψ_i (see Fig.2), i.e.,

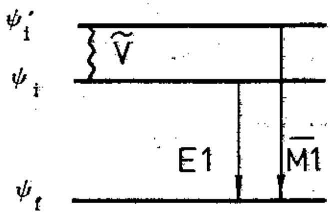

Fig.2

when the initial state function has the form

$$|\bar{\psi}_i> = |\psi_i> + \frac{<\psi_i'|\tilde{V}|\psi_i>}{E_i - E_i'}|\psi_i'> . \qquad (19)$$

First we will show that for $\tilde{N}N$ states with $T_3=0$ ($\tilde{p}p \pm \tilde{n}n$) circular polarization cannot occur, i.e., $P_\gamma = 0$.

Table 2

Charges, e_i, magnetic spin, μ_i and orbital, g_i, moments of $\tilde{N}$ and N; $\mu_p = 2.79$, $\mu_n = -1.91$

	e_i	μ_i	g_i
$\tilde{N}$ (i = 1)	$\frac{1}{2}(-1 + \tau_i^3)e$	$-\frac{1}{2}(\mu_p + \mu_n) + \frac{1}{2}(\mu_p - \mu_n)\tau_i^3$	$\frac{1}{2}(-1 + \tau_i^3)$
N (i = 2)	$\frac{1}{2}(1 + \tau_i^3)e$	$\frac{1}{2}(\mu_p + \mu_n) + \frac{1}{2}(\mu_p - \mu_n)\tau_i^3$	$\frac{1}{2}(1 + \tau_i^3)$

Note, that in the matrix elements $\vec{E}_1$, $\vec{M}_1$ and $\tilde{V}$ (the formulas (16), (17), (18) and (A2)) terms with operator $\tau_1^3 + \tau_2^3$ vanish by virtue of the equality $<T_3'=0|\tau_1^3 + \tau_2^3|T_3=0> = 0$. Considering the remaining terms one may easily find the following spin selection rules: $S_i = S_f$ for E1 transition, $S_i' = S_f \pm 1$ for M1 transition and $S_i' = S_i$ for the mixing operator $\tilde{V}$. As these conditions are noncompatible, the radiation of transitions between $\tilde{p}p \pm \tilde{n}n$ states cannot have circular polarization, i.e., $P_\gamma = 0$.

From an analogous analysis it follows that the E1 and M1 transitions can interfere in the $\tilde{N}N$ systems with $T_3 = 1$ ($\tilde{n}p$) and $T_3 = -1$ ($\tilde{p}n$); and here the toroidal moment is very important. For instance, the E1 transition $^{33}P_1 \to {}^{31}S_0$ occurs only through the spin part of $\vec{T}_1$ (term with $\vec{\sigma}_1 - \vec{\sigma}_2$ in (17)).

Thus, among all the levels of bound states given in ref. [8] only the levels shown in Fig.3 satisfy the selection rules for P_γ.

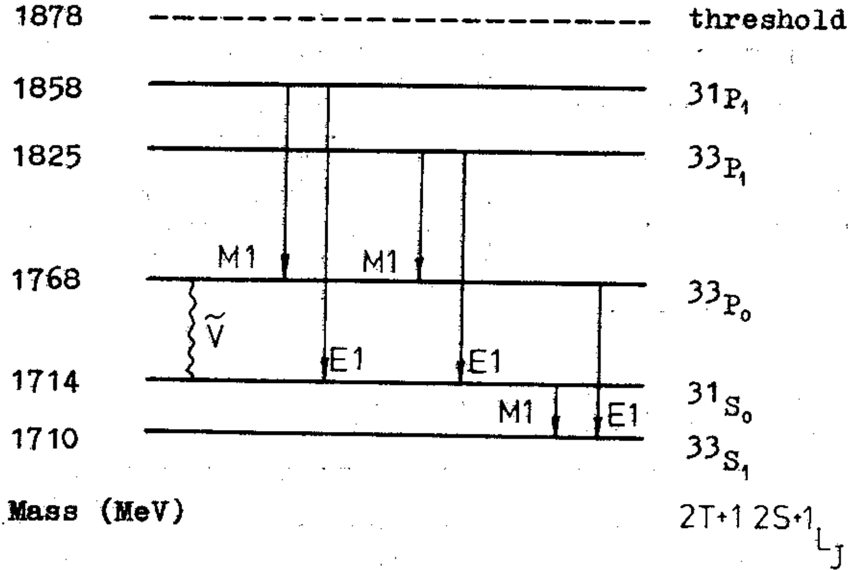

Fig.3

§4. RESULTS AND DISCUSSION

We have calculated the circular polarization of γ-quanta for all the (six) transitions drawn in Fig.3. The calculations were made with the wave functions of quasinuclear system found by I.S.Shapiro with collaborators [8]. Results of the calculations are listed in Table 3.

It is seen that the values of P_γ for transitions in the $\tilde{N}N$ system exceed the calculated P_γ in $np \to d\gamma$ [3] by one or two orders. Here it should be taken into account that the effect depends on the smallest of weak constants c and c′. This increase in P_γ is explained by a more compactness of the $\tilde{N}N$ system as compared to the deuteron. The use of fitted ("best") values of $c=-0.084$ and $c'=-0.20$ from ref.[13] little increases P_γ ($P_\gamma^{fit} \simeq 1.5\, P_\gamma^{theor}$). Note, however, that in view of uncertainty of the $\tilde{N}N$ wave functions at short distances one may expect the PV effect to vary by one order.

We do not discuss here the influence of annihilation widths of levels on the PV effects, as the question on the magnitude of widths is not yet solved (see, e.g., ref.[9]). The degree of statistical suppression of the effects because of the competition of the annihilation channel $Y = \frac{\Gamma_\gamma}{\Gamma_A + \Gamma_\gamma}$ can reach $\sim 10^{-2}$. Note also that the yield of the quasinuclear system onto the upper level from the protonium is also $\sim 10^{-2}$.

Table 3

Calculated values of P_γ for transitions of Fig.3

Transition	$^{31}P_1 \to \overline{^{31}S_0}$		$^{31}P_1 \to \overline{^{33}P_0}$		$^{33}P_1 \to \overline{^{31}S_0}$		$^{33}P_1 \to \overline{^{33}P_0}$		$\overline{^{33}P_0} \to {}^{33}S_1$		$\overline{^{31}S_0} \to {}^{33}S_1$	
Regular	E1		M1		E1($\vec{T}_1$)		M1		E1		M1	
Irregular	$\overleftarrow{M1}$		$\overrightarrow{E1}$		$\overline{M1}$		$\overline{E1}$ ($\vec{T}_1$)		$\overrightarrow{M1}$		$\overline{E1}$	
γ-quantum energy (MeV)	144		90		111		57		58		4	
Parametrization of $P_\gamma \cdot 10^7$	$\pm(3.17\zeta c-2.59c')$		$\mp(60.6\zeta c-49.4c')$		$\pm(92.7\zeta c-75.5c')$		$\mp(1.30\zeta c-1.06c')$		$\mp(4.45\zeta c-3.63c')$		$\pm(400\zeta c-327c')$	
Numerical value of $P_\gamma \cdot 10^7$	I	II	I	II	I	II	I	II	I	II	I	II
	± 0.26	± 0.17	∓ 5.0	∓ 3.3	± 7.7	± 5.0	∓ 0.11	∓ 0.07	∓ 0.37	∓ 0.24	± 33	± 22

Notation: $|\overline{^{31}S_0}\rangle = |^{31}S_0\rangle + \mathcal{F}|^{33}P_0\rangle$, $|\overline{^{33}P_0}\rangle = |^{33}P_0\rangle + \mathcal{F}|^{31}S_0\rangle$ (see formula (19)); upper sign in P_γ is related to $T_3 = 1(\vec{n}p)$, lower to $T_3 = -1(\vec{p}n)$; values of P_γ I and II are cited for $c=c'=-0.20$ and -0.13, resp. (see Appendix).

Let us summarize the specific features we have found for the PV effects in the quasinuclear system: 1) The effects may be of an order 10^{-5}; 2) The annihilation processes apparently suppress the quark-nuclear contribution to the PV effects; 3) Circular polarization P_γ is defined by the constants c and c' thus giving, in principle, a unique possibility of its measurement; 4) At γ-transitions in $\tilde{N}N$ system the toroidal moment plays the nontrivial role; 5) As the γ-quantum polarization arises only in the $\tilde{p}n$ (or $\tilde{n}p$) systems, the target for the antiproton beam should be a nucleus, e.g., deuterium (if the transition of protonium in $\tilde{n}p$ with the π^- emission is suppressed).

In conclusion note that the baryonium could be useful for studying weak $\tilde{N}N$ interactions, and vice versa, the study of weak $\tilde{N}N$ interactions could give the important information on dynamics of strong $\tilde{N}N$ and NN interactions at short distances.

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APPENDIX

We present here the general form of PV NN and $\tilde{N}N$ potentials

NN potential

$$
\begin{aligned}
V = &- \frac{G_\pi g_\pi}{M_N}(\vec{\sigma}_1 + \vec{\sigma}_2)[\vec{p}, f_\pi](\tau_1^+\tau_2^- - \tau_1^-\tau_2^+) - \\
&- \frac{G_V g_\rho}{4M_N}\{(\vec{\sigma}_1 + \vec{\sigma}_2)\{\vec{p}, f_V\}(-\zeta c + 3c')\frac{\tau_1^3 - \tau_2^3}{2} \\
&+ (\vec{\sigma}_1 - \vec{\sigma}_2)\{\vec{p}, f_V\}[4a(\tau_1^+\tau_2^- + \tau_1^-\tau_2^+) + b\tau_1^3\tau_2^3 + \\
&+ (\zeta c + 3c')\frac{\tau_1^3 + \tau_2^3}{2} + 3\zeta d] + i\vec{\sigma}_1 \times \vec{\sigma}_2[\vec{p}, f_V] \times \\
&\times [4\mu_V a(\tau_1^+\tau_2^- + \tau_1^-\tau_2^+) + \mu_V b\tau_1^3\tau_2^3 + (\mu_V\zeta c + 3\mu_S c') \times \\
&\times \frac{\tau_1^3 + \tau_2^3}{2} + 3\mu_S \zeta d]\} .
\end{aligned}
\tag{A1}
$$

$\underline{\tilde{N}N\ \text{potential}}$ (index "1" denotes the antiparticle)

$$\tilde{V} = \frac{G_\pi g_\pi}{M_N}(\vec{\sigma}_1+\vec{\sigma}_2)[\vec{p}, f_\pi](\tau_1^+\tau_2^- - \tau_1^-\tau_2^+) -$$

$$-\frac{G_V g_\rho}{4M_N}\{(\vec{\sigma}_1+\vec{\sigma}_2)\{\vec{p}, f_V\}[-4a(\tau_1^+\tau_2^- + \tau_1^-\tau_2^+) -$$

$$-b\tau_1^3\tau_2^3 - (\zeta c + 3c')\frac{\tau_1^3-\tau_2^3}{2} + 3\zeta d] + \qquad \text{(A2)}$$

$$+(\vec{\sigma}_1-\vec{\sigma}_2)\ \{\vec{p}, f_V\}(\zeta c - 3c')\frac{\tau_1^3+\tau_2^3}{2} +$$

$$+i\vec{\sigma}_1\times\vec{\sigma}_2[\vec{p}, f_V](\mu_V\zeta c - 3\mu_S c')\frac{\tau_1^3+\tau_2^3}{2}\}, \quad \vec{p} = \frac{1}{2}(\vec{p}_1-\vec{p}_2)\ .$$

The notation is the same as in the text, §2; we put $m_\rho = m_\omega \equiv m_V$. Values of weak constants are listed in Table.

A_π	a	b	c=c′	d
0.44	0.86	0.63	-0.20	0.81
2.7÷5.0	1.19	1.73	-0.13	-1.46

The first line contains values calculated within SEWM, the second those calculated with the one-loop gluon corrections. The values of A_π are extracted from ref. [14] the remaining from the second work of ref. [3].

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