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WHAT QUARK THEORY GIVES FOR THE POTENTIAL DESCRIPTION OF THE PARITY VIOLATION IN NN INTERACTIONS

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In the last years the development of the quark theory has started the calculations of the parity-violating (PV) πNN, ρNN, ωNN interaction constants:

$$\mathcal{H}^{PV}_{MNN} = \frac{1}{\sqrt{2}} h^1_\pi \bar{N}(\vec{\tau}\times\vec{\pi})^3 N +$$

$$+ \bar{N}[h^0_\rho \vec{\tau}\vec{\rho}_\mu + h^1_\rho \rho^3_\mu + h^2_\rho \frac{(3\tau^3\rho^3_\mu - \vec{\tau}\vec{\rho}_\mu)}{2\sqrt{6}}]\gamma^\mu\gamma_5 N + \qquad (1)$$

$$+ \bar{N}(h^0_\omega \omega_\mu + h^1_\omega \tau^3 \omega_\mu)\gamma^\mu\gamma_5 N.$$

These constants enter into the PV NN potential and are determined by the matrix elements $\langle MN' | \mathcal{H}^{PV} | N \rangle$, where $\mathcal{H}^{PV}$ is the effective Hamiltonian of the PV quark-quark interactions with $\Delta S = 0$.

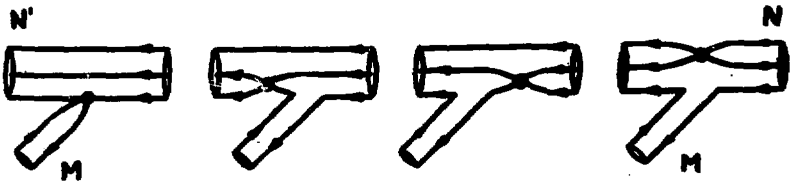
In the standard $SU(2)_L \otimes U(1)$ electroweak model (SEWM) with the inclusion of QCD corrections, $\mathcal{H}^{PV}$ has the form

$$\mathcal{H}^{PV} = \sqrt{2}\, G \sum_{r,i} c^r_i\, \mathcal{O}^r_i . \qquad (2)$$

Here $c^r_i = c^r_i(\sin\theta_C, \sin^2\theta_W;\ \alpha_s(m_c)/\alpha_s(M_W),\ \alpha_s(\mu)/\alpha_s(m_c))$ are coefficient functions depending on the structure of the weak and quark-gluon interactions (μ is a renormalization point of the latter); $\mathcal{O}^r_i$ are local operators; $i = 0,1,2$ is the isotopic index; the index $r = \underline{27}$, $(S, A, 5, 6) \in \underline{8}$, $(1S, 1A) \in \underline{1}$ denotes unitary and colour properties of the operators $\mathcal{O}^r_i$. The quark structures of the vertices (1) are shown in Fig. 1.

The problem of evaluation of the factorizable (F) diagrams (Fig. 1a) has been solved in [1]. However, it is known that the F parts of h_ρ and h_ω cannot explain the experimental data (see, e.g., ref. [2]). As we have shown in ref. [3], the same also concerns $(h^1_\pi)^F$ *.

* As is shown in ref. [3] the known estimates of $(h_\pi)^F$ are overstated because of the use of the chiral symmetry breaking parameters instead of the effective quark masses in the final expression.



a b c d

Fig.1. The black circle stands for $\mathcal{H}^{PV}$; (a) is the factorizable diagram; (b)-(d) are the nonfactorizable diagrams.

The calculation of the nonfactorizable (NF) diagram contributions is a more complicated problem. For the πNN vertex it has been solved in the soft-pion approximation [4,8], which allows the reduction of the NF part of the amplitude $\langle \pi N' | \mathcal{H}^{PV} | N \rangle$ to the one-particle matrix element of a local operator. That reduction is impossible for the vector mesons and one has to apply to other approaches. Recently a unified treatment of h_M has been made [5] in the framework of the $SU(6)_W$ symmetry and nonrelativistic quark approximation. In this paper the NF contributions have been expressed through two parameters found from the known S-wave amplitudes of nonleptonic hyperon decays. Besides, for the best agreement with experimental data, there have been introduced some additional factors imitating the $SU(6)_W$ symmetry breaking. The values of h_M obtained in ref. [5] are known as "best values" and are widely used to evaluate the PV effects in various reactions. Let us show that the constants near the "best values" may be obtained without any fitting parameters.

We use an approach, based on the following approximations:

a) the nonrelativistic reduction of the operators O_i^r and the states $\langle MB'|$ and $|B\rangle$, that permits us to factorize the matrix elements $M_{MB'B} = \langle MB' | O_i^r | B \rangle^{NF}$ in the following way*: $M_{MB'B} = a_{MB'B}\, b_{MB'B}$, where $a_{MB'B}$ is the spin, unitary, and colour part of $M_{MB'B}$, and $b_{MB'B}$ is the spatial part of $M_{MB'B}$;

b) the $SU(6)$ symmetry, which implies all the spatial parts of $M_{MB'B}$ to be equal for all $M \in \underline{35}$ and $B', B \in \underline{56}$, i.e., $b_{MB'B} = b$.

* In this approximation the contribution of the NF diagram (d) into h_M vanishes.

When calculating the matrix elements of the antisymmetric operators $\mathcal{O}^{A}$ and $\mathcal{O}^{1A}$, which determine the NF parts of h_ρ^0 and h_ω^0, we take the value of b from the calculations of the S-wave amplitudes of nonleptonic hyperon decays performed in the MIT bag model [4]. In this case b is proportional to the overlapping integral of quark wave functions $I_{bag} = \int_0^R [u^2(r) + v^2(r)]^2 d^3 r$; its value equals $I_{bag} = 2.6 \times 10^{-3}$ GeV^3. The matrix elements of the mixed operators $\mathcal{O}^6$ and $\mathcal{O}^5$ should be handled with more carefully, because for $\Delta S = 1$ they determine the difference $2(\Lambda_-^0)^{NF} - (\Xi_-^-)^{NF}$. In all the quark models its value is opposite in sign with the experimental results *. Therefore, while calculating the NF contributions to h_M with $\Delta I = 1$, determined by operators $\mathcal{O}^6$ and $\mathcal{O}^5$ we express b through the experimental value $2(\Lambda_-^0)^{NF} - (\Xi_-^-)^{NF}$. The matrix elements of the symmetric operators $\mathcal{O}^{27}$, $\mathcal{O}^8$ and $\mathcal{O}^{18}$ vanish for the NF diagrams by virtue of the antisymmetry of the quark wave functions in baryons (the Pati-Woo argument).

As a result, we obtain the following expressions for $(h_M)^{NF}$ ($\mathcal{O}_i^f$ are defined as in paper [3]):

$$(h_\pi^1)^{NF} = -\sqrt{\frac{2}{3}} \frac{(c^6 - c^5)_{\Delta S=0}}{(c^6 - c^5)_{\Delta S=1}} [2(\Lambda_-^0)^{NF} - (\Xi_-^-)^{NF}], \tag{3a}$$

$$(h_\rho^0)^{NF} = -16 \frac{G}{f_\pi} \left(\frac{1}{\sqrt{3}} c_0^A + c_0^{1A}\right) I_{bag}, \tag{3b}$$

$$(h_\rho^1)^{NF} = -\frac{\sqrt{2}}{3} (h_\pi^1)^{NF}, \tag{3c}$$

$$(h_\rho^2)^{NF} = (h_\omega^0)^{NF} = (h_\omega^1)^{NF} = 0. \tag{3d}$$

Here $(\Lambda_-^0)^{NF}$ and $(\Xi_-^-)^{NF}$ are $(\ )^{exp} - (\ )^{F}$. Let us emphasize, that expressions (3a) had been obtained in [3] without applying to the nonrelativistic picture.

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* Such a discrepancy may be caused not only by approximations of the quark models, but also by the existence of the right-handed hadronic currents different from SEWM currents [6].

Table 1

The values of the constants h_M (the renormalization point of strong interactions is μ=0.35 GeV)

h	F x 10^7	NF x 10^7	(F + NF) x 10^7	"best values" x 10^7
h_π^1	0.055	3.5	3.6	4.6
h_ρ^0	11.0	-21.1	-10.1	-11.4
h_ρ^1	0.13	-1.7	-1.6	-0.19
h_ρ^2	-7.7	0	-7.7	-9.5
h_ω^0	-2.6	0	-2.6	-1.9
h_ω^1	-2.1	0	-2.1	-1.1

The total values of the constants h_M are defined by the sum $h_M = (h_M)^F + (h_M)^{NF}$ and are listed in Table 1. In the last column for comparison we present the "best values". Recall that in ref. /6/ the "best values" were calculated with introducing some parameters, imitating the contribution of the quark loops (of the quark sea) to the matrix elements. In our calculations the quark loops contributions are taken into account through the coefficient functions c_i^f of the effective Hamiltonian (2) ("penguin" terms).

For comparison with the experimental data we use the nuclear matrix elements from paper /7/. Our results are given in Table 2. As the constants h_M and the nuclear matrix elements are calculated up to the factor ~ 2, one may speak about a qualitative agreement of the theoretical and experimental results. However, a final conclusion requires a more exact experimental information, especially from the reaction with $\Delta I = 1$.

We turn particular attention to the ratio of the F to NF contributions in h_M, depending directly on the values of the intriguing parameters - the masses of confined quarks. There is a possibility to differ the contributions by measuring h_ρ^1 (see Table 1). Therefore, the processes with $\Delta I = 1$, where the π-exchange is forbidden by selection rules, (e.g. $N\bar{N}$-reactions /8/) are of a great experimental interest.

Table 2

The experimental and calculated values of the observables (Obs).

Reaction	Obs.	ΔI	Exp.	Theor.
$\vec{p}+p \to p+p$ (E = 15 MeV)	A_L	0,1,2	$(-1.7 \pm 0.6) \times 10^{-7}$	-1.6×10^{-7}
$\vec{n}+p \to d+\gamma$	A_γ	1	$(0.6 \pm 2.1) \times 10^{-7}$	-0.38×10^{-7}
$n+p \to d+\gamma$	P_γ	0,2	$< 0.5 \times 10^{-6}$	0.043×10^{-6}
$^{16}O(2^-) \to {}^{12}C + \alpha$	$\pm\sqrt{\Gamma_\alpha}$	0	$(10 \pm 0.1) \times 10^{-5}$	1.1×10^{-5}
$^{18}F(0^- \to 1^+)$	P_γ	1	$(-0.7 \pm 2.0) \times 10^{-3}$	-3.4×10^{-3}
$^{19}F(\frac{1}{2}^- \to \frac{1}{2}^+)$	A_γ	0,1	$(-8.5 \pm 2.6) \times 10^{-5}$	-19.6×10^{-5}
$^{21}Ne(\frac{1}{2}^- \to \frac{3}{2}^+)$	P_γ	0,1	$(2.3 \pm 2.9) \times 10^{-3}$	-27.6×10^{-3}
$^{41}K(\frac{7}{2}^- \to \frac{3}{2}^+)$	P_γ	0,1,2	$(2.0 \pm 0.4) \times 10^{-5}$	1.9×10^{-5}
$^{175}Lu(\frac{9}{2}^- \to \frac{7}{2}^+)$	P_γ	0,1,2	$(5.5 \pm 0.5) \times 10^{-5}$	6.1×10^{-5}
$^{181}Ta(\frac{5}{2}^+ \to \frac{7}{2}^+)$	P_γ	0,1,2	$(-5.2 \pm 0.5) \times 10^{-6}$	-5.5×10^{-6}

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В рамках кваркового описания мезон-нуклонных вершин рассчитаны константы нарушающих четность πNN, ρNN и ωNN взаимодействий. Вычисления проведены в стандартной электрослабой модели $SU(2)_L \otimes U(1)$ с учетом КХД поправок. Полученные результаты находятся в разумном согласии с экспериментальными.

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The constants of the parity violating (PV) πNN, ρNN and ωNN interactions are calculated in the framework of quark picture based on the standard $SU(2)_L \otimes U(1) \otimes SU(3)_c$ model. Our constants are close to the well-known "best values", which provide a successful fit to the low-energy PV experimental data.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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