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PARITY-VIOLATING $NN\varrho$ COUPLING AND $\frac{1}{2}^-$ RESONANCES DESCRIBED BY QUARK MODELS

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Contributions from $\frac{1}{2}^-$ resonance poles to the parity-violating $NN\varrho$ vertex are estimated by using the harmonic-oscillator quark model to calculate the weak vertex. Results are in very good agreement with our previous results obtained by using the *MIT* bag model. These quark-model-independent estimates show that an additional quark configuration must contribute.

1. Introduction

It is well known[1,2] that reasonable results for parity-violating (*PV*) $NN\varrho$ amplitudes require the introduction of pole contributions as well as the usual factorization approximation. Values for *PV* nucleon-nucleon-vector meson (*NNV*)

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couplings which one wants to reproduce are those found by an extensive semi-empirical analysis[1].

Natural candidates for pole contributions are $\frac{1}{2}^-$ baryon resonances[1,2]. In the past these resonances were described[3] in the framework of the *MIT* bag model. According to the approach[1] based on $SU(6)_W$, $\frac{1}{2}^-$ baryon resonances were not sufficient. $\frac{1}{2}^-$ states containing a quark-antiquark pair (i. e., of the type $qqqq\bar{q}$) should also contribute significantly. It seems that such states are needed for the saturation of current-algebra commutators[1].

The problem of *PV NNV* coupling is closely related with the role of $\frac{1}{2}^-$ $(S = -1)$ resonances in non-leptonic hyperon decays. Recent investigations[1,4] which used both the *MIT* bag model[3] and the harmonic-oscillator (*HO*)[5] quark model concluded that $\frac{1}{2}^-$ excited states did not offer a complete explanation of experiments. Such a situation prompted us to re-examine the *PV NNρ* vertex calculation by using the *HO* model in order to calculate weak vertices and to determine their signs. New results compare well with the results based on the old *MIT* model*. As we discuss in Sect. 3, the overall theoretical situation parallels the conclusions reached for *PV* non-leptonic hyperon decays**. It is gratifying that the general conclusion depends on the general properties of the quark structure of hadrons, irrespective of details of the particular quark-model dynamics.

2. *Formalism*

The general formalism used in this paper closely follows that outlined in Ref. 2, and all relevant formulae can be found there. Differences appear only in the model calculation of weak vertices and matrix elements of currents. The non-relativistic character of the *HO* model requires a non-relativistic expansion of the four-quark operators which constitute the weak hamiltonian H_W; for example,

$$[(\bar{q}q)_i\,(\bar{q}q)_j]_{AV+VA} = \frac{1}{2m}\sum_{i\neq j}(\vec{p}_i' - \vec{p}_j')\cdot\vec{A}'(i,j)\,F_{ij},$$

$$[(\bar{q}q)_i\,(\bar{q}q)_j]_{AV-VA} = \frac{1}{2m}\sum_{i\neq j}[(\vec{p}_i' - \vec{p}_j')\cdot\vec{B}'(i,j) + (-\vec{p}_i' - \vec{p}_j')\cdot\vec{C}'(i,j)]\,F_{ij}.$$

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* In this paper we have corrected our previous results[2] by an overall numerical factor.

** *PV NNπ* coupling is probably strongly dominated by neutral currents and their penguins[6]. $\frac{1}{2}^-$ resonance poles are then minor corrections.

Here, m denotes a quark mass and the other quantities are defined as follows:

$$
\begin{aligned}
A'_+(i,j) &= \frac{-1}{\sqrt{2}}\,[(\sigma^i_x - i\sigma^i_y) - (\sigma^j_x - i\sigma^j_y) - i\,(\sigma^i_y\sigma^j_z - \sigma^i_z\sigma^j_y) + (\sigma^i_x\sigma^j_z - \sigma^i_z\sigma^j_x)],\\
A'_-(i,j) &= \frac{1}{\sqrt{2}}\,[(\sigma^i_x + i\sigma^i_y) - (\sigma^j_x + i\sigma^j_y) - i\,(\sigma^i_y\sigma^j_z - \sigma^i_z\sigma^j_y) - (\sigma^i_x\sigma^j_z - \sigma^i_z\sigma^j_x)],\\
A'_0(i,j) &= \sigma^i_z - \sigma^j_z - i\,(\sigma^i_x\sigma^j_y - \sigma^i_y\sigma^j_x),\\
B'_+(1,2) &= \frac{-1}{\sqrt{2}}\,[(\sigma_{1x} - i\sigma_{1y}) + (\sigma_{2x} - i\sigma_{2y})],\\
B'_-(1,2) &= \frac{1}{\sqrt{2}}\,[(\sigma_{1x} + i\sigma_{1y}) + (\sigma_{2x} + i\sigma_{2y})],\\
B'_0(1,2) &= \sigma_{1z} + \sigma_{2z},\\
C'_+(1,2) &= \frac{-1}{\sqrt{2}}\,[i\,(\sigma_{1y}\sigma_{2z} - \sigma_{1z}\sigma_{2y}) - (\sigma_{1x}\sigma_{2z} - \sigma_{1z}\sigma_{2x})], \qquad (2.1)\\
C'_-(1,2) &= \frac{1}{\sqrt{2}}\,[i\,(\sigma_{1y}\sigma_{2z} - \sigma_{1z}\sigma_{2y}) + (\sigma_{1x}\sigma_{2z} - \sigma_{1z}\sigma_{2x})],\\
C'_0(1,2) &= i\,(\sigma_{1x}\sigma_{2y} - \sigma_{1y}\sigma_{2x}),\\
p_\pm &= \mp\frac{1}{\sqrt{2}}\,(p_x \pm ip_y),\ p_0 = p_z,\\
A_\pm &= \mp\frac{1}{\sqrt{2}}\,(A_x \mp iA_y),\ A_0 = A_z,\\
p\cdot A &= p_0A_0 + p_+A_+ + p_-A_-.
\end{aligned}
$$

$\frac{1}{2}^-$ resonant states are described by a multiplet of 70 states with $l = 1$. Physical non-degenerate states are appropriately weighted mixtures of states from the 70 multiplet. These *HO*-model wave functions are listed in Refs. 5,7* and we intend to use the same notation here. We employ completely antisymmetric wave functions and neglect differences between quark-model masses which are not essential for our purposes. We use the following values of the *HO*-model parameters: $m(u) = m(d) = 0.33$ GeV and $\alpha = 0.32$ GeV.

In Table 1 we list the contributions to the H_W matrix elements coming from various $\frac{1}{2}^-$ states. (The weak hamiltonian H_W is given in Ref. 2.)

* In the $\Delta S = 0$ sector mixing coefficients are not affected by difficulties associated with the antisymmetrization of the basis[8].

TABLE 1.

In units $\alpha^4/m\sqrt{\pi}^3$	$<^2 10\,\|0\|\,p>$	$<^4 8\,\|0\|\,p>$	$<^2 8\,\|0\|\,p>$
0_1	0	12	6
0_2	0	0	0
$0_2'$	0	0	0
0_2^1	0	6	3
0_3^1	0	—16	—8
0_1^1	0	—90	—45
0_1^{15}	1/2	1/2	—1/2
0_3^{15}	—1/2	—1/2	1/2
0_2^{15}	—4/3	—4/3	4/3
0_4^{15}	4/3	4/3	—4/3
10^{-6} GeV	$<\Delta^+\,\|H_w\|\,p>$	$<N_a^+\,\|H_w\|\,p>$	$<N_b^+\,\|H_w\|\,p>$
H_w (QCD)	—0.00105	—0.25994	0.42712

Weak matrix elements

To determine the overall sign of a $\frac{1}{2}^-$ contribution, it is necessary to calculate the matrix element of the ϱ-meson source current, as it has already been described. We use a non-relativistic approximation for the vector current:

$$\bar{u}\vec{\gamma}u \rightarrow \frac{1}{2m}\chi^{\dagger}(\vec{p}\,')\,[\vec{p}\,' - i(\vec{p}\,' \times \vec{\sigma})]\,\chi(\vec{p}). \tag{2.2}$$

The strong coupling constants and their theoretical signs are listed in Table 2.

TABLE 2.

N^*	$\|f_{NN^*\varrho}\|_{exp}$	$\varepsilon^\mu < N^*\|V_\mu^{\varrho^0}\|p>$	$f_{NN^*\varrho}^{theor} = < N^*\|V_\mu^{\varrho^0}\|p> \varepsilon_\mu f_\varrho$
N	5.583	1	5.583
N_a	0.754	—0.2457	—1.3717
N_b	(0.738, 1.260)	—0.2920	—1.6302
Δ	(1.008, 1.594)	—0.0539	—0.3009

Strong vertices

3. *Results and conclusion*

Precise numerical results (see Table 3) depend on several inputs:

(i) As shown in Table 1, weak vertices depend on the model parameters a and $m(u)$. The choice which we have made corresponds to a fit the baryon mass spectrum[5]. This fit is so good that one does not have to distinguish between experimental and theoretical resonance masses, as it was done in Ref. 2.

(ii) Some uncertainty comes from the estimated absolute magnitude of the strong $NN^*\varrho$ coupling which has been extracted from the experimental ratios for the decay $N^* \to N\varrho$[2,9]. This is indicated in Tables 2 and 3.

(iii) In addition there is a general uncertainty associated with the type of quark model which is being used. The uncertainties associated with the model used can be found by comparing results obtained in various quark models. These uncertainties seem to be smaller than expected, because models agree among themselves reasonably well. This model independence is one of the major conclusions of this paper.

It is interesting to relate some dynamical problems from this paper with similar problems appearing in nonleptonic hyperon decays. In these decays, two general approaches are used to describe A (s-wave) and B (p-wave) decay amplitudes. With the quark-model results[10,11], one obtains a reasonable fit of A amplitudes without any resonant states; however, B amplitudes turn out to be too small. In this approach, additional resonant states improve the theoretical values for B amplitudes. In the alternative approach, the weak matrix elements

$$\langle B_f \mid H_W(\Delta S = 1) \mid B_i \rangle$$

have the magnitude which is needed to reproduce B amplitudes only through ground-state baryon poles and A amplitudes are too large. One possible compensation comes from $\frac{1}{2}^-$ or $\frac{3}{2}^+$ baryon poles[7,12]. This works only if the weak matrix elements

$$\langle B \mid H_W(\Delta S = 1) \mid B^* \rangle$$

are large than those calculated[2,10] by using a straightforward application of quark models. One can easily see that such an estimate increases the value of the $\Delta S = 0$ matrix elements (of the type listed in Table 1) and thus leads to a value of h^0 which is considerably larger than that listed in Table 3. This table corresponds to the models[4] which yield a correct fit of A amplitudes.

It is important to compare theoretical results with those found semiempirically[1]:

$$\begin{aligned} -1.452 &< (h_\varrho^0)_p)_p < -1.411, \\ -0.003 &< (h_\varrho^1)_p < 0.008. \end{aligned} \tag{3.1}$$

Theoretical signs and relative magnitudes seem to be in encouraging agreement with empirical values. The absolute magnitude of $(h_\varrho^1)_p$ seems to be somewhat too large; however, we are here dealing with small numbers which cannot be calculated with great accuracy. The absolute magnitude of $(h_\varrho^0)_p$ is too small by about $\frac{1}{2}$. In view of the discussion presented in Refs. 1, 4, this should be taken as a strong indication of the importance of the states containing $q\bar{q}$ pairs. Such states could also appear if QCD soft-gluon exchanges are important[13].

TABLE 3.

	Resonance amplitudes (10^{-6})	N_a contribution $m_{Na} = 1.535$ GeV (*HO*)	N_b contribution $m_{Nb} = 1.700$ GeV (*HO*)	Δ contribution $m_\Delta = 1.650$ GeV (*HO*)	Total contribution (*HO*)	Total contribution (*MIT*)
with *QCD*	$(h_\varrho^0)_p$	0.277	(—0.901, —0.528)	0	(—0.624, —0.251)	(—0.595, —0.514)
	$(h_\varrho^1)_p$	—0.0015	—0.0007, —0.0004)	(—0.0035, —0.0022)	(—0.0057, —0.0042)	(—0.0064, —0.0028)
without *QCD*	$(h_\varrho^0)_p$	0.107	(—0.348, —0.204)	0	(—0.241, —0.097)	(—0.236, —0.191)
	$(h_\varrho^1)_p$	0.0013	(0.0003, 0.0006)	(0.0018, 0.0029)	(0.0035, 0.0048)	(0.0024, 0.0052)

Effective weak $NN\varrho$ vertex

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$NN\varrho$ VEZANJE KOJE NARUŠAVA PARNOST I $\frac{1}{2}^-$ REZONANCE OPISANE KVARKOVSKIM MODELIMA

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Pomoću kvarkovskog modela harmoničkog oscilatora procijenjeni su doprinosi polova $\frac{1}{2}^-$ rezonanci vrhu $NN\varrho$ koji narušava parnost, kako bi se izračunao slabi vrh. Rezultati su u vrlo dobrom slaganju s našim ranijim rezultatima dobivenim pomoću *MIT* modela vreće. Ove procjene, neovisne o modelu, pokazuju da se mora uključiti doprinos dodatne kvarkovske konfiguracije.