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RESONANCE DECAYS INVOLVING VECTOR MESONS*

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A picture of resonance decays using only very general features of the quark model is applied to the case of $1/2^{+}1^{-}$ final states. Recent experiments on $\pi N \rightarrow N\rho$ provide a crucial test of the model, which predicts correctly the dominant spin of the $N\rho$ system in several cases.

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The search for symmetries of decay matrix elements beyond $SU(3)$ has been a part of resonance physics for nearly a decade. Only recently, however, has it become clear that certain relatively modest extensions of $SU(3)$ describe a large body of data fairly well.¹⁻⁴

The picture to which we refer makes some minimal use of the quark model.⁵ A hadron is assumed to decay by the creation out of the vacuum of a $q\bar{q}$ pair with $J^{PC} = 0^{++}$, i.e., a 3P_0 unitary singlet pair. Each final hadron contains one member of this pair. Such a picture^{2,6} arises naturally when duality graphs^{7,6} are endowed with spin.

The above model has $SU(6)_W$ as a limit corresponding to $L_z=0$ for the initial hadron⁸ (the z axis is defined by the final particles in the CM). Physically, this corresponds to the assumption that quarks have no transverse momentum inside a hadron. This assumption appears to contradict experimental data.

When an admixture of $L_z \neq 0$ in the initial hadron is allowed, $SU(6)_W$ is broken in a natural way. The quark L of the initial hadron and that of the 3P_0 pair ($L=1$) couple to various values of final orbital angular momentum ℓ . For final hadron pairs with no internal L , parity conservation requires $\ell = L \pm 1$. The amplitudes corresponding to these two values are related in $SU(6)_W$,⁹ but freed from one another when both $L_z = 0$ and $L_z \neq 0$ decays are allowed. We shall call such a scheme " ℓ -broken $SU(6)_W$ ".¹⁰

The study of baryon resonance decays to $\frac{1}{2}^+ 1^-$ final states is a particularly interesting application of ℓ -broken $SU(6)_W$. Three amplitudes contribute to these decays: two with one ℓ (spin 1/2 and 3/2) and one with the other ℓ (spin 3/2). In $SU(6)_W$ all three of these are

related to one another. In ℓ -broken $SU(6)_W$ the relations between spin 1/2 and spin 3/2 amplitudes for the ℓ that has both of them remain valid. These are easy predictions to test. They do not rely on assumptions about centrifugal barriers, in contrast to most of the previous cases where ℓ -broken $SU(6)_W$ was discussed.^{1-3,10}

The recent availability of data on $\pi N \rightarrow \pi\pi N$, allowing a phase shift analysis of $\pi N \rightarrow \rho N$, makes our predictions of particular relevance at present.

Should the following relations be found violated, the usefulness of the quark model for describing resonance decays^{1,3,12} would be brought into serious question.

Define σ to be the natural parity of the initial baryon: $\sigma = \tau P$, $\tau = (-)^{J-1/2}$ = signature, P = parity. Then the following partial waves contribute to $\frac{1}{2}^+ 1^-$ decays:

$$\sigma = + \quad \left\{ \begin{array}{l} \ell_- \equiv J-3/2: S = 3/2 \\ \ell_+ \equiv J+1/2: S = 1/2, 3/2 \end{array} \right. \quad (1)$$

$$\sigma = - \quad \left\{ \begin{array}{l} \ell_- \equiv J=1/2: S = 1/2, 3/2 \\ \ell_+ \equiv J+3/2: S = 3/2 \end{array} \right. \quad (2)$$

where S is the spin of the $\frac{1}{2}^+ 1^-$ system. Barrier effects will usually suppress the higher partial wave, so that only $\sigma = -$ states will involve detectable $S = 1/2$ and $S = 3/2$ admixtures. Exceptions are the cases $J^P = 1/2^-$, for which only $S = 1/2$ is possible in $\ell = \ell_- = 0$, and $J^P = 1/2^+$, for which ℓ_- is unphysical and ℓ_+ should be observable, with

both spins possible. To summarize, we expect useful spin-ratio predictions for $\frac{1}{2}^+ 1^-$ decays of resonances with

$$J^P = 1/2^+; 3/2^+, 5/2^-, 7/2^+, \dots \quad (3)$$

We define decay amplitudes m_λ with λ the vector meson helicity (and the baryon helicity taken $+1/2$). The total $1/2^+ 1^-$ width is

$$\Gamma = \frac{p}{M^2} \frac{2}{2J+1} \sum_\lambda |m_\lambda|^2 \quad (4)$$

in our normalization. Various choices of multiplet assignment usually are possible for a resonance. For each choice, the amplitudes m_λ may be calculated by standard $SU(6)_W$ methods.^{3,4} The ratios $m_1:m_0:m_{-1}$ are well-defined in each case.

Next one expands m_λ in partial-wave amplitudes $[l]_S$:

$$m_\lambda = \sum_{\ell, S} [l]_S \left(\frac{1}{2}, \frac{1}{2}; 1, -\lambda | S, \frac{1}{2}-\lambda \right) \left(S, \frac{1}{2}-\lambda; \ell, 0 | J, \frac{1}{2}-\lambda \right). \quad (5)$$

The ratios of the three $[l]_S$ amplitudes are thus specified in $SU(6)_W$.

In ℓ -broken $SU(6)_W$, the ratios $[l]_{S_1} / [l]_{S_2}$ for the ℓ with two possible spin values continue to hold.

The following N_P amplitudes in (3) are important experimentally¹¹ between 1700 and 2000 MeV:

$$\begin{array}{llll} 1/2^+, & I = 3/2 & \ell = 1, & S = 1/2 & [\Delta(1910)] \\ 3/2^+, & I = 1/2 & \ell = 1, & S = 1/2 & [N(1860)] \\ 7/2^+, & I = 3/2 & \ell = 3, & S = 3/2 & [\Delta(1950)] \end{array}$$

In each case a particular spin predominates though both are allowed.

Table I summarizes the predictions of $SU(6)_W$ for fractional contributions of each partial wave to the total $N\rho$ partial widths of the states in Eq. (6). It has some interesting features in comparison with the data:

(1) Predominance of $S = 1/2$ for $\Delta(1910)$. No choice between 56, (10,4), $L = 2$ and 70, (10,2), $L = 0$ is possible purely on the basis of the experimental dominance of spin $1/2$. Both assignments are consistent with this result. The influence of the predicted $S = 3/2$ admixture is very different in the two cases, however. For the former assignment, $SU(6)_W$ predicts $\mathcal{M}_0 = 0$, while for the latter one expects $\mathcal{M}_0 / \mathcal{M}_1 = -3/\sqrt{2}$. The neglect of the spin-3/2 amplitude¹¹ thus throws away considerable information in this case.

(2) Favored assignment for $N(1860)$. The experimental dominance of spin $1/2$ in Eq. (7) is consistent with only one assignment of this resonance to a pure state: it must belong to 56, (8,2), $L = 2$. This assignment, interestingly enough, may help to explain the observed suppression of $N(1860) \rightarrow \Delta\pi$, as (by similar methods) it predicts $\Gamma_p[\Delta\pi]/\Gamma[\Delta\pi] = 1/10$, $\Gamma_F[\Delta\pi]/\Gamma[\Delta\pi] = 9/10$ for this state. Even with the expected suppression of F waves, in fact, one might expect some F wave $\Delta\pi$ decay of this state. The fact that none is seen¹¹ may indicate that small admixtures of other $SU(6) \otimes O(3)$ representations are present in $N(1860)$.

(3) Predominance of $S = 3/2$ for $\Delta(1950)$. The assignment shown is the only reasonable one. The result of Table I follows from two conditions

which are expected to hold in general in the present model: $\ell = 5$ decays are absent, and $M_0 = 0$. As in the case of $\Delta(1910)$, information on the relative phase of the $S = 1/2$ and the (smaller) $S = 3/2$ amplitude would be helpful here, to see if M_0 really vanishes.

Further applications of the present method could be envisioned if data were good enough to see the amplitudes neglected in Ref. 11. We envision small contributions from the states listed in Table II. Also presented are predictions for $N\omega$ decays. Since the ω contains a unitary singlet piece, these predictions are based on the ansatz $N \rightarrow N\omega$. Phase shift analyses of the reaction $\pi^- p \rightarrow \omega n$, for example with detection of the $\pi^0 \gamma$ decay of the ω , would thus provide a useful complement to the analysis of Ref. 11. The prediction of dominance of $S = 3/2$ for $N(1860) \rightarrow (N\omega)_{\ell=1}$, given our favored assignment, is one amusing result: recall that $S = 1/2$ was found dominant for N_p decay.

We close with some brief remarks relating our work to that of others.

A recent bootstrap calculation¹³ predicts the dominance of $S = 3/2$ in all the cases of Eq. (6). Hence, although our quark model results may well follow from other "non-quark" arguments (and we would welcome such alternative descriptions) the correct prediction of spin ratios in such schemes is apparently not automatic.

The present method, when combined with the vector dominance model (VDM) predicts relations among photoproduction amplitudes similar but not identical to those of Refs. 12 and 14. The results of the two approaches are compared in Table III for photoproduction of $D_{13}(1520)$ and $F_{15}(1690)$. One linear relation is common to both approaches. In

fact, we suspect that the relations of Refs. 12 and 14 may be correct at $q^2=0$ while our relations should hold only at $q^2=m_\rho^2 \approx m_\omega^2$ where q^2 is the virtual photon mass. Presumably a smooth interpolation holds between the two points. This conjecture would provide a basis for predictions of resonance electroproduction, but requires accurate neutron data for its verification.

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Table Captions

Table I. Fractional contributions of different partial waves to N_f decay predicted by $SU(6)_W$. Pairs of underlined numbers are expected to preserve their ratio in the presence of $SU(6)_W$ breaking. The numbers in the second column refer to: $SU(6)$ representation, $SU(3) \times SU(2)$ representation, and quark orbital angular momentum, respectively.

Table II. Predictions analogous to those of Table I but for as yet unobserved states.

Table III. Comparison of relations for resonance photoproduction amplitudes on neutrons [$\mathcal{M}_\lambda(n)$] in terms of those on protons [$\mathcal{M}_\lambda(p)$]. Note the existence of one linear relation common to both approaches.

Table I

Resonance	Assignment	$\frac{\Gamma[\ell_-]_{1/2}}{\Gamma}$	$\frac{\Gamma[\ell_-]_{3/2}}{\Gamma}$	$\frac{\Gamma[\ell_+]_{1/2}}{\Gamma}$	$\frac{\Gamma[\ell_+]_{3/2}}{\Gamma}^a$
$\Delta(1910): \frac{1}{2}^+$	<u>56</u> , (10,4), L=2	0	0	.67	.33
	<u>70</u> , (10,2), L=0	0	0	.76	.24
$N(1860): \frac{3}{2}^+$	<u>56</u> , (8,2), L=2	.28	.07	0	.65
	<u>70</u> , (8,2), L=2	.02	.10	0	.88
	<u>70</u> , (8,4), L=2	.17	.53	0	.30
	<u>70</u> , (8,4), L=0	.17	.83	0	0
$\Delta(1950): \frac{7}{2}^+$	<u>56</u> , (10,4), L=2	.25	.75	0	0

a: The definitions of $\ell_{\pm}$ are given in Eqs. (1,2).

Resonance; Decay Mode	Assignment	Table II			
		$\frac{\Gamma[\ell_-]_{1/2}}{\Gamma}$	$\frac{\Gamma[\ell_-]_{3/2}}{\Gamma}$	$\frac{\Gamma[\ell_+]_{1/2}}{\Gamma}$	$\frac{\Gamma[\ell_+]_{3/2}}{\Gamma}$ ^a
N(1780): $\frac{1}{2}^+$ → Nρ → Nω	<u>56</u> , (8,2), L=0	0	0	.28	.72
		0	0	.03	.97
	<u>70</u> , (8,2), L=0	0	0	.02	.98
		0	0	.67	.33
	<u>56</u> , (8,2), L=2	.03	.10	0	.87
		.67	.03	0	.30
N(1860): $\frac{3}{2}^+$ → Nω	<u>70</u> , (8,2), L=2				
N(1990): $\frac{7}{2}^+$ → Nρ → Nω	<u>70</u> , (8,4), L=2	.25	.75	0	0
		.25	.75	0	0

a: The definitions of $\ell_{\pm}$ are given in Eqs. (1,2).

Table III

Resonance	Refs. 12, 14	Present work (assuming vector dominance)
$N(1518)$ $D_{13}(1520)$	$M_1(n) = -M_1(p) - M_{-1}(p)/3\sqrt{3}$ $M_{-1}(n) = -M_{-1}(p)$	$M_1(n) = -M_1(p)/3 - 2M_{-1}(p)/3\sqrt{3}$ $M_{-1}(n) = -\frac{2}{3}M_{-1}(p)$
$N(1688)$	$M_1(n) - \frac{1}{\sqrt{3}} M_{-1}(n) = -\frac{1}{3} [M_1(p) - \frac{1}{\sqrt{3}} M_{-1}(p)]$	
$F_{15}(1690)$	$M_1(n) = -\frac{2}{3} M_1(p) + \sqrt{2} M_{-1}(p)/3$ $M_{-1}(n) = 0$	$M_1(n) = -\frac{2}{3} M_1(p) + M_{-1}(p)/3\sqrt{2}$ $M_{-1}(n) = -\frac{1}{3} M_{-1}(p)$
	$M_1(n) - \frac{1}{\sqrt{2}} M_{-1}(n) = -\frac{2}{3} [M_1(p) - \frac{1}{\sqrt{2}} M_{-1}(p)]$	

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