Possible Duality Constraints on P-Wave Nonleptonic Decays

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Assuming minimal exchange-degeneracy patterns for mesons and baryons consistent with duality and the absence of exotic resonances, an argument is given for possible constraints on P-wave nonleptonic baryon decays. The $\Delta I=\frac{1}{2}$ rule and $P(\Sigma_-^-)=0$ then follow in the $SU(3)$ limit.

IT has been suggested[1] that the $\Delta I=\frac{1}{2}$ rule (or suppression of $\Delta I=\frac{3}{2}$ transitions) in nonleptonic decays is a consequence of hadron dynamics satisfying duality and the absence of exotic resonances. The nonleptonic decays are described as a quasihadronic process in which the weak interaction acts like scalar and pseudoscalar spurions. Their matrix elements, like those of hadron scattering, are assumed to obey the hypothesis of duality and no resonances in exotic channels.[2]

It is then possible to show that the transitions involving pseudoscalar 27-plet spurions (0^{--}) are forbidden, thus implying the $\Delta I=\frac{1}{2}$ rule for parity-violating (pv) decays.

However, our argument was not completely successful for parity-conserving (pc) baryon decays in that one cannot generally reject a possible contribution from an s-u dual amplitude.[3] Such a term indeed vanishes for pv baryon decays because of CP invariance[4] but does not for pc decays. It appears that we need *further dynamical assumptions* about the matrix elements of nonleptonic decays in order to derive the $\Delta I=\frac{1}{2}$ rule as well as other selection rules for pc baryon decays.[5]

In this paper, we show that the $\Delta I=\frac{1}{2}$ rule and the absence of $\Sigma^-\rightarrow n+\pi^-$ mode for pc decays can be proved in the $SU(3)$ limit, provided we introduce minimal degeneracy patterns for meson and baryon trajectories obtained from and consistent with duality, factorization, and positivity conditions on meson-baryon (M-B) scattering.[6]

Before going into the details of our discussion, we summarize the $SU(3)$ exchange-degeneracy scheme for meson and baryon trajectories, which has been extensively studied recently.[6] Meson trajectories contributing in the t channel in question are of abnormal parity, for which we have two exchange-degenerate 0^{-+}-1^{+-} and 1^{++}-2^{--} nonet trajectories.[7] For baryon trajectories, we take the "minimal" solutions obtained from s-u duality

$$[\mathbf{8}_\alpha(\tfrac{1}{2}^+,\tfrac{5}{2}^+,\ldots)-(\mathbf{8}+\mathbf{1})_\gamma(\tfrac{3}{2}^-,\tfrac{7}{2}^-,\ldots)]$$

and

$$[\mathbf{10}_\delta(\tfrac{3}{2}^+,\tfrac{7}{2}^+,\ldots)-\mathbf{8}_\beta(\tfrac{5}{2}^-,\tfrac{9}{2}^-,\ldots)]$$

exchange degeneracy.[8] It will be noted that the F/D ratios $f\equiv F/(F+D)$ of the couplings for $\mathbf{8}_\alpha-\mathbf{8}_\gamma$ and $\mathbf{8}_\beta$ trajectories with octet 0^- mesons and $\frac{1}{2}^+$ baryons are also fixed by s-u duality and predicted to be $\frac{1}{2}$ and $-\frac{1}{2}$, respectively.

Let us now slightly extend the above coupling scheme by postulating that for mesons lying on a trajectory the coupling F/D ratios with octet $\frac{1}{2}^+$ baryons are all the same; in other words, the F/D ratios are constant along

[1] K. Kawarabayashi and S. Kitakado, Phys. Rev. Letters **23**, 440 (1969); **23**, 1007(E) (1969). See also S. Nussinov and J. L. Rosner, *ibid.* **23**, 1264 (1969).

[2] As usual, we assume the universal current×current theory of weak interactions and consider separately the scattering involving octet and 27-plet scalar (0^{++}) and pseudoscalar (0^{--}) spurions. We are aware of the fact that additional singularities usually not associated with purely hadronic scattering may appear for nonhadronic processes. In this respect, our assumptions should be considered as a working hypothesis. However, in view of the fact that there is no reliable dynamical model for pc nonleptonic decays, we think it worthwhile to work along the line presented in this paper.

[3] See the erratum in Ref. 1.

[4] It is well known that CP invariance in the universal current ×current theory of weak interactions imposes restrictions for S-wave decays. See, e.g., M. Suzuki, Phys. Rev. **137**, B1602 (1965).

[5] A summary and earlier references on phenomenological analysis of P-wave decays can be found in A. Murayama, Progr. Theoret. Phys. (Kyoto) **43**, 125 (1970), and in a talk given at the Meeting on Weak Interactions of Elementary Particles, Kyoto, 1970 (unpublished).

[6] J. Mandula, J. Weyers, and G. Zweig, Phys. Rev. Letters **23**, 266 (1969); R. H. Capps, *ibid.* **22**, 215 (1969); V. Barger and C. Michael, Phys. Rev. **186**, 1592 (1969); J. L. Rosner, Phys. Rev. Letters **24**, 173 (1970); M. Rimpault and Ph. Salin, Bordeaux report (unpublished).

[7] Nonet structure for abnormal-parity trajectories does not fit well into the observed meson-mass spectrum. In fact, 0^{-+} and 1^{++} mesons, which belong to abnormal-parity series, seem to obey almost pure octet patterns. See, however, the remarks stated at the end of this paper.

[8] We have adopted here the "minimal" solution for exchange-degenerate patterns of baryons. It is possible, however, to include $\mathbf{10}_\gamma(\frac{3}{2}^-,\frac{7}{2}^-,\ldots)$ and $\mathbf{8}_\delta(\frac{3}{2}^+,\frac{7}{2}^+,\ldots)$ trajectories. Our conclusions are insensitive to including these perturbations. See J. L. Rosner, Phys. Rev. D **1**, 2701 (1970).

the trajectory. An immediate consequence is then that all mesons lying on the 0^{-+}-1^{+-} trajectory must have a universal coupling ratio with octet $\frac{1}{2}^+$ baryons and predicted value $f_1=\frac{1}{2}$. For mesons lying on the 1^{++}-2^{--} trajectory, we observe that the Goldberger-Treiman relation implies

$$(F/D)_{\text{axial-vector current}}=(F/D)_{\text{pseudoscalar meson coupling}}. \quad (1)$$

Thus, if the axial-vector current is indeed dominated by 1^{++} mesons, one may conclude that mesons lying on the 1^{++}-2^{--} trajectory have the same coupling F/D ratio (f_2) as that of 0^{-+}-1^{+-} trajectory, namely, $f_2=\frac{1}{2}$.[9]

Keeping these hadron spectra and couplings in mind, let us first consider the process

$$B(\mathbf{8})+S(\mathbf{27})\to B(\mathbf{8})+M(\mathbf{8}), \quad (2)$$

where $S(\mathbf{27})$ stands for a scalar 27-plet spurion (0^{++}) with $I=\frac{3}{2}$ and $Y=+1$. It has been shown in the previous paper that absence of resonances in exotic channels requires all the s-t and u-t dual amplitudes to vanish.[1] The s-u dual amplitudes, on the other hand, will not vanish on general grounds alone, but it is not difficult to see that there is only a *single s-u dual amplitude* consistent with the absence of exotic resonances.[10] As a result, all nonexotic s-u dual amplitudes are proportional to each other and are expressed as

$$\text{Im}A^s(\mathbf{10})=-(8/5)\,\text{Im}A^s(\mathbf{8})=+(8/\sqrt{5})\,\text{Im}A^s(\mathbf{8}'), \quad (3)$$

where $A^s(\mathbf{I})$ ($I=10$, 8, and 8′) are the $SU(3)$ eigenamplitudes in the s channel for the process (2).

A crucial observation then is the following: With the s-u dual term alone, it is not possible to construct the amplitude $A^s(\mathbf{10})$ [or $A^u(\mathbf{10})$] with the correct signature factor for the $\mathbf{10}_\delta$ trajectory, since, as noted before, $\mathbf{10}_\delta$ is exchange degenerate with $\mathbf{8}_\beta$. Hence, **10** poles should be completely absent in the s (u) channel, leading to $A_{\mathbf{10}}{}^S(s,u)=0$. Combined with Eq. (3), this implies that all the s-u dual amplitudes should vanish, thus completing the proof of the $\Delta I=\frac{1}{2}$ rule for pc baryon decays.

We turn now to a problem of $P(\Sigma_-^-)$, the P-wave or pc nonleptonic decay of the Σ^-, and consider the process

$$B(\mathbf{8})+S(\mathbf{8})\to B(\mathbf{8})+M(\mathbf{8}), \quad (4)$$

where $S(8)$ is the scalar octet spurion (0^{++}). We then calculate the absorptive part of **10** component of amplitudes for the process (4) in the s channel, and find

$$\text{Im}A^s(\mathbf{10})=(2f_1-1)a^t(\mathbf{8}_1)+(2f_2-1)a^t(\mathbf{8}_2), \quad (5)$$

where $(2f_i-1)a^t(\mathbf{8}_i)$ ($i=1$, 2) are the absorptive parts of the amplitudes in which 0^{-+}-1^{+-} and 1^{++}-2^{--} trajectories are exchanged in the t channel. The f_1 and f_2 are the universal-coupling F/D ratios mentioned before. It is now clear from Eq. (5) that with the predicted common value $f_1=f_2=\frac{1}{2}$, the s-t dual amplitude has no **10** component:

$$A_{\mathbf{10}}{}^S(s,t)=0. \quad (6)$$

Similar reasoning, with which we have shown $A_{\mathbf{10}}{}^S(s,u)=0$ for the process (2), can then be applied to the present case and leads to the conclusion that the **10** component of the amplitudes for Eq. (4) is completely absent in the s (u) channel.

In order to show $P(\Sigma_-^-)=0$, it is sufficient to note that $n\pi^-$ is a pure $I=\frac{3}{2}$ state and there is no planar u-t duality diagram for $\Sigma^-+\kappa^0\to n+\pi^-$, where κ^0 is the scalar spurion with $I=\frac{1}{2}$ and $Y=+1$.

We close this paper with a few remarks.

(a) In deriving Eq. (5), we have assumed the ideal nonet coupling of abnormal-parity mesons with the octet $\frac{1}{2}^+$ baryons. However, for a process such as $\Sigma^-+\kappa^0\to n+\pi^-$, this assumption can be dropped without altering our conclusion, provided abnormal-parity meson trajectories exchanged in the t channel continue to keep their common F/D value, $f_1\simeq f_2\simeq\frac{1}{2}$, consistent with observations. One can then apply and repeat the previous arguments at the $SU(2)$ level, again leading to the fact that $\Sigma^-+\kappa^0\to n+\pi^-$ is a forbidden process.

(b) From experimental grounds, it appears that not only abnormal-parity mesons but also normal-parity mesons lying on the 1^{--}-2^{++} exchange-degenerate trajectory couple with the octet $\frac{1}{2}^+$ baryons with a universal F/D value.[11] Its value is, however, free from the duality constraints on M-B scattering and is interpreted as a freedom of the relative contribution of normal- and abnormal-parity baryon trajectories in the s channel.[6]

On the other hand, the empirical equality of the F/D value for the octet pc weak and semistrong spurion coupling with octet $\frac{1}{2}^+$ baryons[12] suggests that this F/D value ($\approx\frac{3}{2}$) would persist for particles lying on the (first) daughter trajectory. Assuming this to be the case, one will then find that, for each pc decay amplitude, the contributions from ground states of baryons and mesons in the s (u) and t channels cancel each other.[13] Hence the pc amplitudes must receive main contributions from higher excited states of baryons and mesons. We note, in passing, that the universal F/D coupling scheme discussed here is not identical with the assumption that pc weak and semistrong interactions both belong to an octet scalar.

(c) We have seen that the $\mathbf{10}_\delta$ contribution, which is

[9] A recent fit to hyperon semileptonic decays gives $f\simeq0.40$, consistent with our assumption. See F. Eisele, R. Engelmann, H. Filthuth, W. Föhlisch, V. Hepp, E. Leitner, W. Presser, H. Schneider, M. Stevenson, and G. Zech, Z. Physik **225**, 383 (1969).

[10] This can easily be verified by writing the s-u duality diagram for this process.

[11] V. Barger, M. Olsson, and K. V. L. Sarma, Phys. Rev. **147**, 1115 (1966).

[12] Y. Hara, Y. Nambu, and J. Schechter, Phys. Rev. Letters **16**, 380 (1966); M. Nakagawa and N. N. Trofimenkoff, Nuovo Cimento **50A**, 657 (1967); S. Furui and N. N. Trofimenkoff, Progr. Theoret. Phys. (Kyoto) **42**, 1485 (1969).

[13] S. Coleman and S. L. Glashow, Phys. Rev. **134**, B671 (1964); B. W. Lee, *ibid.* **140**, B152 (1965); S. L. Adler and R. F. Dashen, *Current Algebras* (Benjamin, New York, 1968), p. 130.

certainly present in the process $0^-(\mathbf{8})+\frac{1}{2}^+(\mathbf{8}) \to 0^-(\mathbf{8}) +\frac{1}{2}^+(\mathbf{8})$, should decouple from the process $0^+(\mathbf{8}) +\frac{1}{2}^+(\mathbf{8}) \to 0^-(\mathbf{8})+\frac{1}{2}^+(\mathbf{8})$. At first sight, this appears to conflict with the factorization, since, according to our scheme, there is a nonvanishing **10** contribution for the process $0^+(\mathbf{8})+\frac{1}{2}^+(\mathbf{8}) \to 0^+(\mathbf{8})+\frac{1}{2}^+(\mathbf{8})$. An obvious solution, consistent with the factorization, will be to assume another **10** trajectory coupled strongly to $0^+(\mathbf{8})$-$\frac{1}{2}^+(\mathbf{8})$ but not to $0^-(\mathbf{8})-\frac{1}{2}^+(\mathbf{8})$. However, discussions about implied physical consequences are beyond the scope of this paper.

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πN Charge-Exchange Polarization in the Veneziano Model

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Pion-nucleon charge-exchange polarization is calculated in various Veneziano representations for πN scattering. Our results are in qualitative agreement with the expermiental data for some sets of parameters. It is not possible, however, to resolve the nonuniqueness of the Veneziano representation from this information alone.

I. INTRODUCTION

It is well known that in a process like $\pi^- p \to \pi^0 n$, in the t channel only one Regge pole can be exchanged —in this case the pole corresponding to the ρ trajectory —and consequently the phases of the spin-nonflip and the spin-flip amplitudes should be equal. This results in a vanishing polarization at high energies where the Regge-pole model becomes applicable. However, there is experimental evidence of nonvanishing polarizations at pion laboratory energies of 5.9 and 11.2 GeV/c, although single-Regge-pole fits are good for differential cross sections at these energies.

Several models have been proposed to explain both the polarization and the differential cross sections for the charge-exchange process. All of them involve adding a background term to the ρ-trajectory contribution, and justify such an addition. The addition[1] of a secondary trajectory ρ' with the same quantum number as that of the ρ trajectory, but with a different intercept, can introduce the required phase difference between the spin-flip and spin-nonflip amplitudes without changing the cross section significantly. An alternative model[2] requires a Regge cut—which presumably is connected with the Gribov-Pomeranchuk phenomenon—to provide the necessary background. A fairly successful model[3] was to treat the polarization as arising from the interference between the Regge-trajectory contribution and the direct-channel resonances occurring on indefinitely rising baryon trajectories. It may be recalled that in this model the significant contributions were derived from the resonances in the neighborhood of the energy value, and that the Breit-Wigner tails of the resonances were not important.

The Veneziano model for the scattering amplitude explicitly contains both the resonance poles corresponding to a rising trajectory and the Regge asymptotic behavior. Naturally we should expect that it automatically contains the necessary interference terms to give the appropriate polarization. Indeed, polarization could form one of the stringent tests for the Veneziano model. However, it is not possible to write a unique Veneziano representation.

We make a comparative study of various Veneziano representations for πN charge-exchange scattering with respect to their prediction for polarization.

II. IGI'S MODEL

We first consider Igi's model[4] for the πN invariant amplitudes A and B. These are obtained by requiring (a) crossing symmetry, (b) Regge asymptotic behavior at high energies, and (c) constraints implied by isospin. We use ρ and f trajectories in the t channel and N_α, Δ_δ, and N_γ trajectories in the s and u channel; we identify amplitudes with t-channel isospin $I_t=0$ (1) by means of

[1] R. K. Logan, J. Beaupre, and L. Sertorio, Phys. Rev. Letters 18, 259 (1967).
[2] C. B. Chiu and J. Finkelstein, Nuovo Cimento 48A, 820 (1967).
[3] B. R. Desai, D. T. Gregorich, and R. Ramachandran, Phys. Rev. Letters 18, 565 (1967).
[4] K. Igi, Phys. Letters 28B, 330 (1968).