Weak decays of $1/2^+$ and $3/2^+$ baryons in SU(4) dynamical scheme

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(Received 9 July 1980)

Two-body weak decays of baryons are studied in a simple SU(4) dynamical scheme. Expressing the decay amplitudes in terms of eigenamplitudes in s, t, and u channels and assuming that the nonexotic intermediate states contribute dominantly, we find that the Glashow-Iliopoulos-Maiani weak Hamiltonian vanishes for the parity-violating (PV) decay mode. Starting with the most general weak Hamiltonian ($\underline{15}\otimes\underline{15}$), we then obtain $\underline{15}$ dominance for the PV mode of uncharmed baryons including Ω^-, whereas the charmed-hadron decays occur through $\underline{15}_A$, $\underline{45}_A$, $\underline{45}^*_A$. For the parity-conserving mode, we obtain $\underline{20}''$ dominance of the weak Hamiltonian. However, uncharmed-baryon decays demand a $\underline{15}_S$ admixture. We predict null asymmetry for $B(3)\to B(3^*)+P(8)$, $B(3)\to B(6)+P(8)$, $B(3)\to D(10)+P(3^*)$, $B(3)\to B(8)+P(3^*)$, and $B(3^*)\to D(10)+P(8)$, and for Ω_3^{*++} decays. We also notice that only π^+/ρ^+-emitting decays are allowed in the PV mode.

I. INTRODUCTION

It is widely believed that leptonic and semileptonic weak interactions are described by the simplest model of weak and electromagnetic interactions.[1] However, the issue of the $\Delta I=\frac{1}{2}$ or octet dominance in nonleptonic weak interactions is not settled yet. Recent results[2] on Ω^- decays indicate a $\Delta I=\frac{1}{2}$ violation of about 20%. The mesonic decays $K_S\to 2\pi$ and nonzero asymmetry parameter $\alpha(\Sigma^+\to p\gamma)$ have also defied a simple understanding for a long time.

Some of the attempts made to understand the nonleptonic processes are the following. (i) In quantum chromodynamics (QCD), an enhancement of the $\Delta I=\frac{1}{2}$ piece does occur at short distances but numerical estimates are too small to account for the observation. Strong-interaction corrections due to gluon exchange have been considered by Shifman *et al.* to explain this discrepancy.[3] Gluon corrections seem to explain Ω^- data well also.[4] (ii) Using duality with nonexotic intermediate states, an enhancement for nonexotic spurion can be obtained[5] which in the Hamiltonian language means octet dominance of the SU(3) weak Hamiltonian. But it has been shown by Ellis, Gaillard, and Nanopoulos[6] that similar arguments run into difficulty when applied to the charmed-particle decays. For instance, the Cabibbo-enhanced decays belonging to the exotic representations, such as $\underline{20}''$, $\underline{45}$, $\underline{45}^*$, $\underline{84}$ of SU(4), are suppressed in such considerations. (iii) An addition of unconventional currents[7,8] can explain octet dominance, $K_S\to 2\pi$, and the large asymmetry parameter for the $\Sigma^+\to p\gamma$ decay. For the charmed-hadron decays these currents would introduce a new piece of the weak Hamiltonian transforming like ($\underline{45}+\underline{45}^*$) in SU(4), which may explain the experimental features of the charmed-meson decays.[9] But in the presence of these representations the predictive power of SU(4) is decreased, as now all the representations present in $\underline{15}\otimes\underline{15}$ contribute to the weak interaction. Moreover, so far there is no explicit experimental evidence for these currents.

In an earlier work[10] most of the observed features of the nonleptonic decays of ordinary baryons have been obtained using simple dynamical assumptions. The effective Hamiltonian is treated as a spurion S and the decay $B\to B'+P$ is related to the process $S+B\to B'+P$. The decay amplitudes are expressed in terms of reduced matrix elements corresponding to each intermediate state in all the s, t, and u channels. The weak Hamiltonian ($\underline{8}+\underline{27}$) with the nonexoticity of the intermediate states[11] and the s-u channel symmetry[12] gives well-satisfied results such as the Lee-Sugawara sum rule for the parity-violating (PV) as well as the parity-conserving (PC) modes and $\Sigma_+^+=0$ for the PV mode and $\sqrt{2}\Sigma_+^+-\Sigma_0^+=\sqrt{3}\Lambda_-^0$ for the PC mode. The important features of this model are that it simultaneously, explains the $\Delta I=\frac{1}{2}$ rule for $\frac{1}{2}^+$ baryons and allows $\Delta I=\frac{1}{2}$ violation in Ω^- decays. In addition, we notice that the PV decays occur only through the t channel, whereas the PC decays obtain dominant contributions from the s and u channels. These results are in accordance with the results of current-algebra[13] and duality arguments.[5] A similar structure for the PV and the PC decays has also been obtained in the constituent-rearrangement quark model.[14]

Encouraged by the success of our model in SU(3), we also explored the structure of the weak Hamiltonian in SU(4) symmetry.[9] For the PV weak decays of hadrons, starting with the most general Hamiltonian, we find that the Glashow-Iliopoulos-Maiani (GIM) contributions vanish totally and the decays occur through $\underline{15}_A$, $\underline{45}_A$, $\underline{45}^*_A$ antisymmetric representations. In particular for D-meson decays, we obtain[9] $\langle K^-\pi|D^0\rangle|\langle \bar{K}^0\pi^+|D^+\rangle=1$ and $\langle \bar{K}^0\pi^0|D^0\rangle=0$. The experimental[15] branching ratios are $B(D^+\to\bar{K}^0\pi^+)=(1.5\pm0.6)\%$, $B(D^0\to K^-\pi^+)=(2.2\pm0.6)\%$, and $B(D^0\to\bar{K}^0\pi^0)=(2.0\pm0.9)\%$ whereas the conventional GIM picture[16] gives $\langle K^-\pi^+|D^+\rangle=-\sqrt{2}\langle\bar{K}^0\pi^0/D^0\rangle$ and $\langle\bar{K}^0\pi^+|D^+\rangle=0$. These antisymmetric representations may arise through unconventional current[7,8] or symmetry breaking[17a] or may be induced through gluon exchange[3] or Higgs-boson exchange,[17b] or via a Melosh transformation on a left-handed quark.[17c]

In this paper we discuss the weak decays of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons in SU(4) dynamical scheme. Because of the heavy mass of the charm quark, new channels open up for the charm-changing decays of $\frac{1}{2}^+$ baryons, e.g., in addition to $B(\frac{1}{2}^+)\to B(\frac{1}{2}^+)+P(0^-)$ channel, $\frac{1}{2}^+$ baryons can decay through $B(\frac{1}{2}^+)\to D(\frac{3}{2}^+)+P(0^-)$, $B(\frac{1}{2}^+)\to B(\frac{1}{2}^+)+V(1^-)$, and $B(\frac{1}{2}^+)\to D(\frac{3}{2}^+)+V(1^-)$ also. In the charm sector, we obtain decay amplitudes for this channel for $\Delta C=\Delta S$ mode. Out of $\frac{3}{2}^+$ charmed isobars, Ω_1^{*0}, Ω_2^{*+}, Ω_3^{*++} are expected to decay through weak interaction. We consider the weak decays of these isobars only. In Sec. II, we present the preliminaries and the method. Sections III–VI describe the nonleptonic decays of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons. In the last section we give a summary and conclusion.

II. PRELIMINARIES

A. Method

We treat the effective nonleptonic weak Hamiltonian as a symmetry-breaking spurion S and the decay $B\to B'+P$ as the process $S+B\to B'+P$. The transition amplitudes are then expressed in terms of reduced amplitudes in s, t, and u channels of the process corresponding to each intermediate state[18] $|m\rangle$ and are defined as follows:

$$\begin{aligned}&\langle B'||P||m\rangle\langle m||S||B\rangle, &&\text{for } s \text{ channel } (S+B\to m\to B'+P),\\ &\langle P||\bar{S}||m\rangle\langle m||\bar{B}'||B\rangle, &&\text{for } t \text{ channel } (\bar{B}'+B\to m\to\bar{S}+P),\\ &\langle B'||\bar{S}||m\rangle\langle m||\bar{P}||B\rangle, &&\text{for } u \text{ channel } (B+\bar{P}\to m\to B'+\bar{S}).\end{aligned} \quad (2.1)$$

The baryonic intermediate states appear in the s and u channels while the mesons are exchanged in the t channel. We assume that the main contribution to the decays comes through the single-particle nonexotic intermediate states.[11] Thus only $\underline{4^*}$, $\underline{20'}$, $\underline{20}$ baryonic multiplets occur as the intermediate states in the s and u channels, while singlet and fifteen-plet mesons are exchanged in the t channel. Secondly, we assume that the weak Hamiltonian is symmetric in s and u channels.[12] Mathematically speaking, this essentially amounts to

$$\langle B'||P||m\rangle\langle m||S||B\rangle=\langle B'||\bar{S}||m\rangle\langle m||\bar{P}||B\rangle, \quad (2.2)$$

i.e., identical reduced matrix elements appear in s and u channels.

B. Weak Hamiltonian

The general current $\otimes$ current weak-interaction Hamiltonian can belong to the SU(4) representations present in the direct product

$$\underline{15}\otimes\underline{15}=\underline{1}_S\oplus\underline{15}_S\oplus\underline{15}_A\oplus\underline{20}''_S\oplus\underline{45}_A\oplus\underline{45}^*_A\oplus\underline{84}_S. \quad (2.3)$$

The conventional GIM Hamiltonian transforms like

$$H_w^{\mathrm{GIM}}\sim\underline{20}''\oplus\underline{84} \text{ for PV and PC modes.} \quad (2.4)$$

In the presence of unconventional currents, the weak Hamiltonian may acquire additional components

$$\begin{aligned}&H_w^{\mathrm{PV}}\sim\underline{15}_A\oplus\underline{45}_A\oplus\underline{45}^*_A \text{ for PV mode,}\\ &H_w^{\mathrm{PC}}\sim\underline{15}_S\oplus\underline{20}''_S\oplus\underline{84}_S \text{ for PC mode.}\end{aligned} \quad (2.5)$$

However, in our analysis, we consider the most general weak Hamiltonian belonging to all the representations, present in the direct product (2.3). We do not enter into the detailed origin of these various components and simply obtain symmetry constraints on these pieces due to our dynamical assumptions.

III. DECAY AMPLITUDES: $B(\frac{1}{2}^+)\to B(\frac{1}{2}^+)+P(0^-)$

Among the charmed baryons, we discuss the nonleptonic weak decays of $B(3^*)$ and $B(3)$ multiplets only, since the present mass spectroscopy of hadrons[19] allows all the particles except Ω_1^0 of $B(6)$ multiplet to decay to $B(3^*)$ through strong and/or electromagnetic interactions.[20]

A. The GIM model

The weak Hamiltonian transforms like $(\underline{20}''+\underline{84})$ for both the PV as well as the PC modes. In SU(4), the GIM weak Hamiltonian can be written as

$$
\begin{aligned}
H_w^{20''} = {} & a_1[\overline{B}^c_{[a,b]} B^{[n,d]}_m P^m_n H^{[a,b]}_{[c,d]}] \\
& + a_2[\overline{B}^m_{[a,b]} B^{[n,c]}_m P^d_n H^{[a,b]}_{[c,d]}] \\
& + a_3[\overline{B}^m_{[a,b]} B^{[c,d]}_n P^n_m H^{[a,b]}_{[c,d]}] \\
& + a_4[\overline{B}^m_{[n,b]} B^{[c,d]}_a P^n_m H^{[a,b]}_{[c,d]}] \\
& + a_5[\overline{B}^n_{[m,a]} B^{[c,d]}_n P^m_b H^{[a,b]}_{[c,d]}] \\
& + a_6[\overline{B}^c_{[m,n]} B^{[m,n]}_a P^d_b H^{[a,b]}_{[c,d]}] \\
& + a_7[\overline{B}^m_{[n,a]} B^{[n,c]}_m P^d_b H^{[a,b]}_{[c,d]}] ,
\end{aligned}
\tag{3.1}
$$

$$
\begin{aligned}
H_w^{84} = {} & b_1[\overline{B}^c_{[e,f]} B^{[e,f]}_a P^d_b H^{(a,b)}_{(c,d)}] \\
& + b_2[\overline{B}^c_{[f,a]} B^{[e,d]}_b P^f_e H^{(a,b)}_{(c,d)}] \\
& + b_3[\overline{B}^e_{[a,f]} B^{[c,f]}_e P^d_b H^{(a,b)}_{(c,d)}] \\
& + b_4[\overline{B}^e_{[a,f]} B^{[c,f]}_b P^d_e H^{(a,b)}_{(c,d)}] \\
& + b_5[\overline{B}^c_{[a,f]} B^{[d,f]}_e P^e_b H^{(a,b)}_{(c,d)}] \\
& + b_6[\overline{B}^c_{[e,f]} B^{[e,d]}_a P^f_b H^{(a,b)}_{(c,d)}] \\
& + b_7[\overline{B}^c_{[e,a]} B^{[e,f]}_b P^d_f H^{(a,b)}_{(c,d)}] .
\end{aligned}
\tag{3.2}
$$

CP invariance demands

$$
\begin{aligned}
& a_1=-a_4, \quad a_2=-a_5, \quad a_3=a_6=a_7=0, \\
& b_4=-b_5, \quad b_6=-b_7, \quad b_1=b_2=b_3=0
\end{aligned}
\tag{3.3}
$$

for the PV mode and

$$
\begin{aligned}
& a_1=a_4, \quad a_2=a_5, \\
& b_4=b_5, \quad b_6=b_7
\end{aligned}
\tag{3.4}
$$

for the PC mode. The nonexoticity of the intermediate states yields

$$
\begin{aligned}
& a_4=a_5=a_6=a_7=0, \\
& b_3=b_5=0, \quad b_2=b_6, \quad 2b_1=-b_7 \quad \text{for the } s \text{ channel,}
\end{aligned}
\tag{3.5}
$$

$$
\begin{aligned}
& a_1=a_2=a_3=a_4=a_5=0, \\
& b_2=b_4=b_5=b_6=b_7=0 \quad \text{for the } t \text{ channel,}
\end{aligned}
\tag{3.6}
$$

and

$$
\begin{aligned}
& a_1=a_2=a_6=a_7=0, \\
& b_3=b_4=0, \quad 2b_1=-b_6, \quad b_2=b_7 \quad \text{for the } u \text{ channel.}
\end{aligned}
\tag{3.7}
$$

(i) Parity-violating decays. It is clear from the conditions (3.3) to (3.7) that the CP invariance and the absence of exotic intermediate states forbid $\underline{20}''$ and $\underline{84}$ components of the weak Hamiltonian from contributing in all the s, t, and u channels. Thus the PV decays of the charmed and uncharmed $\frac{1}{2}^+$ baryons are forbidden in the GIM model. The same result is obtained for the case of mesonic decays also.[9] But this result is in conflict with the experiment as the PV decays have been observed. In the next sections we discuss the probable origin of these decays from the representations other than those present in the GIM model.

(ii) Parity-conserving decays. We have seen[10] in SU(3) that the t-channel contribution is very small in the case of PC decays. Small t-channel contributions are understandable here, as only unnatural-parity Reggeon exchange is allowed in the t channel of the scattering[14] $(S+B \to B'+\pi)$. Since the contributions described by Regge exchange are expected to be considerably small as a result of the low intercept of the unnatural-parity meson trajectories, individual contributions from low-lying poles and resonances may be important as in the nuclear force and in low-energy πN scattering.

Ignoring the t channel in the PC mode, we observe that $\underline{84}$ component of the weak Hamiltonian vanishes when we assume the nonexoticity of the intermediate states and the s-u channel symmetry (Eq. 2.2) of the weak Hamiltonian. Thus $\underline{20}''$ dominance of the PC Hamiltonian is obtained, which expresses all the PC decays of charmed and uncharmed baryons in terms of just one parameter. We get the following amplitude relations *for the uncharmed decays*:

$$
\begin{array}{ccccccccc}
\Lambda^0_- & : & \Sigma^+_+ & : & \Sigma^-_- & : & \Xi^-_- & = \frac{1}{\sqrt{6}} : 1 : 0 : 0 . \\
(9.98 \pm 0.24) & & (19.04 \pm 0.16) & & (-0.65 \pm 0.08) & & (-6.70 \pm 0.38) &
\end{array}
\tag{3.8}
$$

This result has earlier been obtained by Kohara.[21] *For the $\Delta C = \Delta S$ decays*, in addition to the relations obtained[22] at the SU(3) level by assuming $\underline{6}^*$ dominance, we get the sum rule

$$
\begin{aligned}
0 & = \langle \Xi^0 \pi^0 | \Xi'^0_1 \rangle = \langle \Xi^- \pi^+ | \Xi'^0_1 \rangle = \langle \Xi^0 \pi^+ | \Xi'^+_1 \rangle = \langle \Sigma^+ \overline{K}^0 | \Xi'^+_1 \rangle = \langle p \overline{K}^0 | \Lambda'^+_1 \rangle \\
& = \langle \Xi'^+_1 \overline{K}^0 | \Omega^+_2 \rangle = \langle \Xi'^0_1 \pi^+ | \Xi^+_2 \rangle = \langle \Xi'^+_1 \pi^0 | \Xi^+_2 \rangle = \langle \Xi'^+_1 \eta | \Xi^+_2 \rangle = \langle \Lambda'^+_1 \overline{K}^0 | \Xi^+_2 \rangle \\
& = \langle \Xi'^+_1 \pi^+ | \Xi^{++}_2 \rangle = \langle \Omega^0_1 \pi^+ | \Omega^+_2 \rangle = \langle \Xi^+_1 \overline{K}^0 | \Omega^+_2 \rangle = \langle \Xi^0_1 \pi^+ | \Xi^+_2 \rangle \\
& = \langle \Xi^+_1 \pi^0 | \Xi^+_2 \rangle = \langle \Xi^+_1 \eta | \Xi^+_2 \rangle = \langle \Sigma^+_1 \overline{K}^0 | \Xi^+_2 \rangle = \langle \Sigma^{++}_1 K^- | \Xi^+_2 \rangle = \langle \Xi^+_1 \pi^+ | \Xi^{++}_2 \rangle ,
\end{aligned}
\tag{3.9}
$$

$$\sqrt{6}\langle\Lambda\pi^+|\Lambda'^+_1\rangle=-\sqrt{2}\langle\Sigma^0\overline{K}^0|\Xi'^0_1\rangle=-\sqrt{3/2}\langle\Xi^0\eta|\Xi'^0_1\rangle=\frac{1}{\sqrt{6}}\langle\Sigma^+D^0|\Xi^+_2\rangle=\frac{1}{\sqrt{6}}\langle\Xi^0F^+|\Xi^+_2\rangle=-\frac{1}{\sqrt{3}}\langle\Xi'^+_1\eta'|\Xi^+_2\rangle. \tag{3.10}$$

Notice that the decay channels $B(3)\to B(6)+P(8)$ and $B(3)\to B(3^*)+P(8)$ are forbidden. The computed decay amplitudes for the channels $B(3^*)\to B(8)+P(8)$ and $B(3)\to B(8)+P(3^*)$ are displayed in Table I.

B. 15 admixture to the GIM model

As we have seen in the last section, the PV decays are forbidden in the GIM model, in conflict with experiment. In the PC mode although $\Sigma^-_-=0$ is obtained, other decay amplitudes in (3.8) do not agree with experiment, as Ξ^-_- is not zero and Λ^0_-, Σ^+_0 are also off by 25%. In SU(4) symmetry alone also, the GIM model does not work well, as the Iwasaki relation[23]

$$\Lambda^0_-:\Sigma^+_0:\Xi^-_-=1:-\sqrt{3}:2 \tag{3.11}$$

is violated by about 40%. Besides these, the GIM model faces difficulties in explaining D-meson decays[24] and forbids the PV $\overline{N}N\pi$ vertex, whereas experimentally the parity violation in nuclear forces ($\overline{N}N\pi$) is well established.[25] In order to explain such discrepancies of the GIM model, the suggestion to include 15 admixture has been made.[17,26] This 15 admixture may arise through incomplete cancellation in $(\bar{d}u\bar{u}s-\bar{d}c\bar{c}s)$ due to large mass difference in u and c quarks.[17] 15 weak Hamiltonian has the components

$$\begin{aligned}H^{15}_w={}&A_1[\overline{B}^m_{[n,c]}B^{[b,c]}_aP^n_mH^a_b]+A_2[\overline{B}^m_{[c,d]}B^{[c,d]}_aP^b_mH^a_b]+A_3[\overline{B}^m_{[d,a]}B^{[b,d]}_cP^c_mH^a_b]+A_4[\overline{B}^b_{[m,c]}B^{[c,d]}_aP^m_dH^a_b]\\&+A_5[\overline{B}^c_{[m,d]}B^{[b,d]}_cP^m_aH^a_b]+A_6[\overline{B}^c_{[m,a]}B^{[b,d]}_cP^m_dH^a_b]+A_7[\overline{B}^m_{[c,d]}B^{[c,d]}_mP^b_aH^a_b]+A_8[\overline{B}^b_{[c,d]}B^{[c,d]}_mP^m_aH^a_b]\\&+A_9[\overline{B}^m_{[a,d]}B^{[d,c]}_mP^b_cH^a_b]+A_{10}[\overline{B}^b_{[a,d]}B^{[d,n]}_mP^m_nH^a_b].\end{aligned} \tag{3.12}$$

CP invariance leads to the conditions

$$A_1=A_{10},\ A_2=-A_8,\ A_5=A_9,\qquad A_3=A_4=A_6=A_7=0 \tag{3.13}$$

for the PV mode and

$$A_1=-A_{10},\ A_2=A_8,\ A_5=-A_9 \tag{3.14}$$

for the PC mode. Absence of the exotic intermediate states gives

$$2A_7=2A_8=A_9=A_{10},\qquad A_5=A_6\ \text{for the } s \text{ channel}, \tag{3.15}$$

$$A_1=A_3=A_4=A_6=A_{10}\ \text{for the } t \text{ channel}, \tag{3.16}$$

$$2A_7=2A_2=-A_5=-A_1,\qquad A_9=-A_6\ \text{for the } u \text{ channel}. \tag{3.17}$$

(i) Parity-violating decays. Under CP invariance, H^{15}_w satisfies the Lee-Sugawara sum rule in all the channels. For the s and u channels, the following relations are obtained:

$$-\sqrt{6}\,\Lambda^0_-:2\sqrt{3}\,\Lambda^0_0=\sqrt{6}\,\Xi^-_-=2\sqrt{3}\,\Xi^0_0=-\sqrt{2}\,\Sigma^+_0=\Sigma^+_+. \tag{3.18}$$

Since Σ^+_+ is found to be zero experimentally,[27] the effective contribution of the s and u channels to these decays seems to be small. We, in fact, notice that the s-u channel symmetry, leading to

$$A_1=-A_{10},\ A_2=A_8,\ A_5=-A_9,\ A_3=A_4, \tag{3.19}$$

forbids the s and u channels to contribute in the PV mode. This result is in accordance with the results of duality arguments[5] and current algebra.[13] Using duality arguments, Nussinov and Rosner[5] have shown that for the s-wave decay the low-energy pole contribution is relatively small and that the Regge contribution dominates. In the current-algebra[13] framework the PV decays get contribution from the equal-time-commutator term which in our analysis corresponds to the t channel, where the nonexoticity of the intermediate states leads to $\Sigma^+_+=0$ in addition to the Lee-Sugawara sum rule

$$\sqrt{3}\,\Sigma^+_0-\Lambda^0_-=-2\,\Xi^-_-. \tag{3.20}$$

TABLE I. $\Delta C=\Delta S$, PC decay amplitudes.

Decay	GIM model	15 admixture to GIM model
$\Lambda'^+\to\Sigma^+\pi^0$	23.53	4.59
$\to\Lambda\pi^+$	13.59	2.65
$\to\Sigma^0\pi^+$	−23,53	−4.59
$\to\Xi^0K^+$	33.28	6.49
$\to\Sigma^+\eta$	13.59	2.65
$\to\Sigma^+\eta'$	9.61	1.87
$\Xi'^0\to\Sigma^+K^-$	33.28	6.49
$\to\Lambda\overline{K}^0$	13.59	2.65
$\to\Sigma^0\overline{K}^0$	−23.53	−4.59
$\to\Xi^0\eta$	−27.17	−5.30
$\to\Xi^0\eta'$	9.61	1.87
$\Xi^+_2\to\Sigma^+D^0$	81.51	15.90
$\to\Lambda D^+$	33.28	6.49
$\to\Sigma^0D^+$	−57.64	−11.24
$\to\Xi^0F^+$	81.51	15.90

For the case of the charmed baryons the $\Delta C = \pm \Delta S$ decays are still forbidden. The charm-changing mode $\Delta C = -1$, $\Delta S = 0$ occurring in $\underline{15}$, also remains forbidden even in the presence of SU(4) breaking, since $\underline{15}$ cancellation seems to persist for $(c \to u)$ weak Hamiltonian as the propagators, for d and s quarks in the expression $\sin\theta_C \cos\theta_C(\bar{u}\, d\bar{d}c - \bar{u}s\bar{s}c)$, remain degenerate. Thus in our analysis the charm-changing PV decays of charmed baryons are not allowed in the GIM picture of the weak interaction.

(ii) Parity-conserving mode. In the presence of $\underline{15}$ admixture, nonzero Ξ^-_- is obtained. Assuming the absence of exotic intermediate states, $H_w^{15+20''}$ leads to a new relation

$$\sqrt{2}\,\Sigma^+_+ - \Sigma^+_0 = \sqrt{3}\,\Lambda^0_- \tag{3.21}$$

(14.91 ± 0.82) (17.61 ± 0.41)

which has earlier been obtained in SU(3) framework[10] in s and u channels. Experimental validity of the relation (3.21) shows that t-channel contribution is small. In the presence of t channel, a nonzero $\Delta I = \frac{3}{2}$ contribution appears which may explain the small $\Delta I = \frac{1}{2}$ violation observed in the recent $\Xi^0 \to \Lambda\pi^0$ experiment.[28] We would like to remark here that the s-u channel symmetric (Eq. 3.19) weak Hamiltonian[10] belonging to adjoint representations also satisfies the Lee-Sugawara sum rule (3.21), unlike the $\underline{20}''$ part of the weak Hamiltonian. We can thus conclude that the octet projections from $\underline{15}$ and $\underline{20}''$ at the SU(3) level are not the same. D/F ratios for these two representations are different.[29]

The charm-particle decays remain unaffected owing to the $\underline{15}_S$ cancellation in the GIM framework. In column 2 of Table I we have listed the decay amplitudes of charmed baryons in the presence of SU(4)-symmetry breaking. The values are smaller than given in column 1, since, due to the $\underline{15}$ contribution to the uncharmed sector, effective value of $\underline{20}''$ reduced matrix elements is decreased.

C. Unconventional interactions

We have shown that the PV charm-changing decays of baryons are not allowed to occur in the GIM model. The same result has also been obtained for mesonic decays.[9] But this is in sharp conflict with the experiment, since the PV charm-changing D-meson decays have been seen in experiments. A possible way out is to look for other representations present in the direct product (2.3). In the following we consider the antisymmetric representations $\underline{45}$ and $\underline{45}^*$ which appear in a particular combination, such as $\underline{45} + \underline{45}^*$. The weak Hamiltonian in the $\underline{45}$ and $\underline{45}^*$ representations have the components

$$\begin{aligned} H_w^{45} = {} & d_1[\bar{B}^c_{[e,f]} B^{[e,f]}_a P^d_b H^{[a,b]}_{(c,d)}] \\ & + d_2[\bar{B}^c_{[f,a]} B^{[e,d]}_b P^f_e H^{[a,b]}_{(c,d)}] \\ & + d_3[\bar{B}^e_{[a,f]} B^{[c,f]}_e P^d_b H^{[a,b]}_{(c,d)}] \\ & + d_4[\bar{B}^e_{[a,f]} B^{[c,f]}_b P^d_e H^{[a,b]}_{(c,d)}] \\ & + d_5[\bar{B}^c_{[a,f]} B^{[d,f]}_e P^e_b H^{[a,b]}_{(c,d)}] \\ & + d_6[\bar{B}^c_{[e,f]} B^{[e,d]}_a P^f_b H^{[a,b]}_{(c,d)}] \\ & + d_7[\bar{B}^c_{[e,a]} B^{[e,f]}_b P^d_f H^{[a,b]}_{(c,d)}] \\ & + d_8[\bar{B}^d_{[a,b]} B^{[m,c]}_n P^n_m H^{[a,b]}_{(c,d)}] \,, \end{aligned} \tag{3.22}$$

$$\begin{aligned} H_w^{45*} = {} & d'_1[\bar{B}^c_{[e,f]} B^{[e,f]}_a P^d_b H^{(a,b)}_{[c,d]}] \\ & + d'_2[\bar{B}^c_{[f,a]} B^{[e,d]}_b P^f_e H^{(a,b)}_{[c,d]}] \\ & + d'_3[\bar{B}^e_{[a,f]} B^{[c,f]}_e P^d_b H^{(a,b)}_{[c,d]}] \\ & + d'_4[\bar{B}^e_{[a,f]} B^{[c,f]}_b P^d_e H^{(a,b)}_{[c,d]}] \\ & + d'_5[\bar{B}^c_{[a,f]} B^{[d,f]}_e P^e_b H^{(a,b)}_{[c,d]}] \\ & + d'_6[\bar{B}^c_{[e,f]} B^{[e,d]}_a P^f_b H^{(a,b)}_{[c,d]}] \\ & + d'_7[\bar{B}^c_{[e,a]} B^{[e,f]}_b P^d_f H^{(a,b)}_{[c,d]}] \\ & + d'_8[\bar{B}^m_{[n,a]} B^{[c,d]}_b P^n_m H^{(a,b)}_{[c,d]}] \,. \end{aligned} \tag{3.23}$$

CP invariance gives the relation

$$\begin{aligned} & d_1 = d'_1, \quad d_2 = -d'_2, \quad d_3 = d'_3, \quad d_4 = -d'_5 \,, \\ & d_5 = d'_4, \quad d_6 = d'_7, \quad d'_7 = -d'_6, \quad d_8 = d'_8 \end{aligned} \tag{3.24}$$

for the even-charge-conjugation ($C = +1$) parity of weak spurion. The nonexoticity of the intermediate states yields

$$\begin{aligned} & 2d_1 = d_7, \quad -d_2 = d_6, \quad d_3 = d_5 = d_8 = 0 \,, \\ & d'_2 = d'_6, \quad d'_1 = d'_3 = d'_5 = d'_7 = 0 \quad \text{for the } s \text{ channel} \,, \end{aligned} \tag{3.25}$$

$$\begin{aligned} & d_2 = d_4 = d_5 = d_6 = d_7 = d_8 = 0 \,, \\ & d'_2 = d'_4 = d'_5 = d'_6 = d'_7 = d'_8 = 0 \quad \text{for the } t \text{ channel} \,, \end{aligned} \tag{3.26}$$

$$\begin{aligned} & d_2 = d_7, \quad d_1 = d_3 = d_4 = d_6 = 0 \,, \\ & -2d'_1 = d'_6, \quad d'_2 = d'_7, \; d'_3 = d'_4 = d'_8 = 0 \quad \text{for the } u \text{ channel} \,. \end{aligned} \tag{3.27}$$

Employing CP invariance and the nonexoticity of the intermediate states, we notice that $\underline{45}$, $\underline{45}^*$ do not contribute in s and u channels and so the PV decays arise only through t channel. We are then able to express the decay amplitudes in terms of two parameters. In addition to the relations obtained earlier[30] in SU(3), we have

$$\begin{aligned} 0 & = \langle \Xi^+_1 \bar{K}^0 | \Omega^+_2 \rangle = \langle \Sigma^+_1 \bar{K}^0 | \Xi^+_2 \rangle = \langle \Sigma^{++}_1 \bar{K}^0 | \Xi^{++}_2 \rangle \\ & = \langle \Xi'^+_1 \bar{K}^0 | \Omega^+_2 \rangle = \langle \Xi'^+_1 \bar{K}^0 | \Xi^+_2 \rangle = \langle p\bar{K}^0 | \Lambda'^+_1 \rangle \\ & = \langle \Sigma^+ \bar{K}^0 | \Xi'^+_1 \rangle = \langle \Lambda\bar{K}^0 | \Xi'^0_1 \rangle = \langle \Sigma^0 \bar{K}^0 | \Xi'^0_1 \rangle \\ & = \langle \Sigma^+ \pi^0 | \Lambda'^+_1 \rangle \,, \end{aligned} \tag{3.28}$$

$$\sqrt{3}\,\langle \Xi'^0_1 \pi^+ | \Xi^+_2 \rangle = \langle \Xi^0_1 \pi^+ | \Xi^+_2 \rangle + \langle \Xi^0 \pi^+ | \Xi'^+_1 \rangle \,, \tag{3.29}$$

$$\langle \Omega^0_1 \pi^+ | \Omega^+_2 \rangle = \sqrt{2}\,\langle \Xi^0_1 \pi^+ | \Xi^+_2 \rangle \,. \tag{3.30}$$

Notice that the weak Hamiltonian allows only those decays of charmed baryons in which π^+ is emitted and so the decay channel $B(3)\to B(8)+P(3^*)$ is totally forbidden in the PV mode. A similar result has been obtained in the SU(8) quark model.[31] In a quark model, single-quark transition allows only π^+-emitting decays in the PV mode. Thus for the most general weak Hamiltonian $(\underline{15}+\underline{20}''+\underline{45}+\underline{45}^*+\underline{84})$, we predict that the PV decays of charmed baryon in the Cabibbo-enhanced mode, emitting pseudoscalar mesons other than π^+, would have null asymmetry. This result presents a good test of our dynamical assumptions.

The representations $\underline{45}$, $\underline{45}^*$ may appear in the weak Hamiltonian in several ways such as SU(4) breaking,[17] through the second-class currents[8] and the right-handed current,[7] etc. Although there is no evidence for the right-handed current (RHC) involving u and d quarks from the study[32] of neutral-current data within $SU(2)\times U(1)$, the possibility of a RHC of kind $\bar{s}\gamma_\mu(1+\gamma_5)c$ is not ruled out[33,34] by any experiments. In the D semileptonic decays[35] the effect of charmed RHC is most direct. The y distribution of dimuon events in $\nu_\mu N$ scattering[36] do allow a large $(V+A)$ admixture.[33] It may therefore be worth looking at phenomena such as nonleptonic decays, which could shed light on the (V,A) structure of the $(\bar{c}s)$ current. But then, in addition to $\underline{45}$ and $\underline{45}^*$, $\underline{15}_A$ component would also appear in these unconventional interactions. $\underline{15}_A$ can contribute to $\Delta C=0$, $\Delta S=1$ and $\Delta C=-1$, $\Delta S=0$. In the case of the uncharmed sector, the presence of $\underline{15}_A$ representation allows s and u channels to contribute to these decays. We notice that under the s-u channel symmetry (Eq. 3.19) and the nonexoticity of the intermediate states, the Lee-Sugawara sum rule remains valid in all the three channels; however, Σ_+^+ now obtains a nonzero contribution through s and u channels. We would like to remark, however, that the effective contribution to Σ_+^+ remains small. Extending our consideration to the SU(8) [effectively SU(6) for the uncharmed sector] we obtain

$$\Sigma_+^+=\frac{\sqrt{6}\Lambda_-^0+3\sqrt{2}\Sigma_0^+}{14}=-0.19+0.02\,, \tag{3.31}$$

whereas the experimental value of Σ_+^+ is 0.07. A welcoming feature of the presence of $\underline{15}_A$ is that the decays $\Sigma^+\to P\gamma$ and $K_S\to 2\pi$ are allowed to occur in the PV mode. Thus a nonzero asymmetry can be obtained for $\Sigma^+\to P\gamma$ decay.

$\underline{45}$, $\underline{45}^*$ may also contribute to the uncharmed sector, which gives rise to a nonzero $\Delta I=\frac{3}{2}$ contribution through the t channel. For the PV mode, the t channel relates the discrepancies in the following manner:

$$\begin{array}{ccccc} \sqrt{3}/2\,\Delta\Sigma & = & -(\Delta\Lambda+2\,\Delta\Xi) & = & \Delta(\mathrm{LS})\,,\\ (-0.269\pm0.126) & & (-0.201\pm0.162) & & (0.037\pm0.136)\end{array} \tag{3.32}$$

where

$$\Delta\Sigma=\sqrt{2}\Sigma_0^+-\Sigma_+^++\Sigma_-^-\,,$$
$$\Delta\Lambda=\sqrt{2}\Lambda_0^0+\Lambda_-^0\,,$$
$$\Delta\Xi=\sqrt{2}\Xi_0^0-\Xi_-^-\,,$$
$$\Delta(\mathrm{LS})=\sqrt{3}\Sigma_0^+-\Lambda_-^0+2\Xi_-^-\,.$$

Since the PV decay amplitudes of $\frac{1}{2}^+$ baryons obey the $\Delta I=\frac{1}{2}$ rule and the Lee-Sugawara (LS) sum rule, the contribution from $(\underline{45}+\underline{45}^*)$ piece should be small. Actually if $\underline{45}$, $\underline{45}^*$ representations are considered to be arising from **left** $\otimes$ **right** current-current interaction, we find that the $\Delta C=0$, $\Delta S=-1$ decays acquire no contribution from these representations. Therefore $\underline{15}$ dominance for the PV decays of uncharmed baryons follows in our analysis. The charmed-baryonic decays occur through $\underline{15}_A$, $\underline{45}$, $\underline{45}^*$ pieces. However, the results (3.28)–(3.30) for $\Delta C=\Delta S$ decays remain unaffected in the presence of $\underline{15}_A$.

Parity-conserving decays. The parity-conserving weak Hamiltonian arising from the unconventional left $\otimes$ right current-current interactions transform like

$$H_w^{\mathrm{LR}}\sim\underline{15}_S\oplus 20''+\underline{84}\,.$$

We have shown in Sec. III A that the $\underline{84}$ component of the weak Hamiltonian vanishes under the nonexoticity of the intermediate states (Eqs. 3.5–3.7) and the s-u channel symmetry [Eq. (2.2)] of the weak Hamiltonian. The effect of $\underline{15}_S$ representation is the same as shown in Sec. III B. For the uncharmed decays the relation (3.21) follows and $\Delta C=\Delta S$ decay mode remains unaffected.

In order to make our study most general, we include the antisymmetric representations $\underline{15}_A$, $\underline{45}$, $\underline{45}^*$ in the PC mode too. We observe that under our dynamical assumptions their contribution vanishes.

Finally we conclude that the most general weak Hamiltonian $(\underline{1}+\underline{15}+\underline{20}''+\underline{45}+\underline{45}^*+\underline{84})$ forbids $B(3)\to B(3^*)+P(8)$, $B(3)\to B(6)+P(8)$, and $B(3)\to B(8)+P(3^*)$ in the PC and the PV modes, respectively, therefore predicting null asymmetry parameter for all the two-body decays of $B(3)$ multiplets. In the PV mode, the most general weak Hamiltonian allows only π^+-emitting weak decays of charmed hadrons.

IV. DECAY AMPLITUDES $D(\frac{3}{2}^+)\to D(\frac{3}{2}^+)+P(0^-)$

A. GIM model

The GIM weak Hamiltonian $(\underline{20}''+\underline{84})$ has the components

$$H_w^{20''} = a_1[\bar{D}^{mnc}D_{mna}P_b^d H^{[a,b]}_{[c,d]}], \tag{4.1}$$

$$\begin{aligned} H_w^{84} = & b_1[\bar{D}^{mnc}D_{mna}P_b^d H^{(a,b)}_{(c,d)}] \\ & + b_2[\bar{D}^{mcd}D_{mna}P_b^n H^{(a,b)}_{(c,d)}] \\ & + b_3[\bar{D}^{mcp}D_{mab}P_p^d H^{(a,b)}_{(c,d)}] \\ & + b_4[\bar{D}^{mcd}D_{nab}P_m^n H^{(a,b)}_{(c,d)}]. \end{aligned} \tag{4.2}$$

CP invariance gives

$$a_1 = 0, \quad b_1 = b_4 = 0, \quad b_2 = -b_3 \quad \text{for the PV mode}, \tag{4.3}$$

$$b_2 = b_3 \quad \text{for the PC mode}, \tag{4.4}$$

and nonexoticity of the intermediate states leads to

$$a_1 = 0,$$

$$b_1 = b_2 = 0, \quad \text{for the } s \text{ channel}, \tag{4.5}$$

$$b_2 = b_3 = b_4 = 0, \quad \text{for the } t \text{ channel}, \tag{4.6}$$

$$a_1 = 0, \quad b_1 = b_3 = 0, \quad \text{for the } u \text{ channel}. \tag{4.7}$$

Ω^- decays. In the PV decay mode, we notice that $\underline{20''}$ does not contribute to the weak Hamiltonian under CP invariance alone. $\underline{84}$ part of weak Hamiltonian also vanishes under nonexoticity of the intermediate states. Hence the GIM weak Hamiltonian gives null contribution. In the case of the parity-conserving mode, we notice that Ω^- decays are forbidden in the s and u channels, and so arise only through the t channel. Since t-channel contribution for the PC decays is expected to be small, these decays are suppressed. The possible way out is to add $\underline{15}$ admixtures, arising through SU(4) breaking.[17] It has the following components:

$$\begin{aligned} H_w^{15} = & c_1[\bar{D}^{mnp}D_{mnp}P_b^a H^b_a] \\ & + c_2[\bar{D}^{mna}D_{mnp}P_b^p H^b_a] \\ & + c_3[\bar{D}^{mnp}D_{mnb}P_p^a H^b_a] \\ & + c_4[\bar{D}^{map}D_{mbq}P_p^q H^b_a]. \end{aligned} \tag{4.8}$$

CP invariance gives

$$c_1 = c_4 = 0, \quad c_2 = -c_3 \quad \text{for the PV mode}, \tag{4.9}$$

$$c_2 = c_3 \quad \text{for the PC mode}, \tag{4.10}$$

and nonexoticity of the intermediate states leads to

$$c_1 = c_2 = 0 \quad \text{for the } s \text{ channel}, \tag{4.11}$$

$$c_4 = 0 \quad \text{for the } t \text{ channel}, \tag{4.12}$$

$$c_1 = c_3 = 0 \quad \text{for the } u \text{ channel}. \tag{4.13}$$

Notice that the nonexoticity of the intermediate states forbids s and u channels and all the PV decays arise only through the t channel. Ω^- decays satisfy the $\Delta I = \frac{1}{2}$ relation:

$$\langle \Xi^{*0}\pi^- | \Omega^- \rangle = -\sqrt{2}\langle \Xi^{*-}\pi^0 | \Omega^- \rangle. \tag{4.14}$$

But the PC decays of Ω^- still remain forbidden, indicating null asymmetry. The Cabibbo-enhanced decay mode ($\Delta C = \Delta S$) also remains forbidden in the presence of SU(4) breaking. For the charm sector, we further include the unconventional representations $\underline{45}$, $\underline{45}^*$ which have the following components:

$$\begin{aligned} H_w^{45} = & d_1[\bar{D}^{mnc}D_{mna}P_b^d H^{[a,b]}_{(c,d)}] \\ & + d_2[\bar{D}^{mcd}D_{mna}P_b^n H^{[a,b]}_{(c,d)}], \end{aligned} \tag{4.15}$$

$$\begin{aligned} H_w^{45*} = & d_1'[\bar{D}^{mnc}D_{mna}P_b^d H^{(a,b)}_{[c,d]}] \\ & + d_2'[\bar{D}^{mnc}D_{mab}P_n^d H^{(a,b)}_{[c,d]}]. \end{aligned} \tag{4.16}$$

CP invariance leads to

$$d_1 = d_1', \quad d_2 = d_2'$$

for the even-charge-conjugation ($C = +1$) parity of the PV spurion. The nonexoticity of the intermediate states imposes

$$d_1 = d_2 = 0, \quad d_1' = 0 \quad \text{for the } s \text{ channel}, \tag{4.17}$$

$$d_2 = d_2' = 0 \quad \text{for the } t \text{ channel}, \tag{4.18}$$

$$d_1' = d_2' = 0, \quad d_1 = 0 \quad \text{for the } u \text{ channel}. \tag{4.19}$$

Notice that the nonexoticity of the intermediate states forbids the $\underline{45}$, $\underline{45}^*$ part of the weak Hamiltonian in the s and u channels. The PV decays arise only through the t channel. Among the charmed isobars, the present mass spectrum may allow isosinglet $\Omega_1^{*0}, \Omega_2^{*+}, \Omega_3^{*++}$ to decay weakly. We obtain

$$\begin{aligned} 0 = \langle \Xi^{*0}\bar{K}^0 | \Omega_1^{*0} \rangle = & \langle \Xi_1^{*+}\bar{K}^0 | \Omega_2^{*+} \rangle \\ = & \langle \Xi_2^{*++}\bar{K}^0 | \Omega_3^{*++} \rangle, \end{aligned} \tag{4.20}$$

$$\langle \Omega^-\pi^+ | \Omega_1^{*0} \rangle = \langle \Omega_1^{*0}\pi^+ | \Omega_2^{*+} \rangle = \langle \Omega_2^{*+}\pi^+ | \Omega_3^{*++} \rangle. \tag{4.21}$$

Notice that here also only π^+-emitting decays are allowed. In case of the PC mode, we notice that the most general weak Hamiltonian ($\underline{20''} + \underline{45} + \underline{45}^* + \underline{84}$) forbids $\Delta C = \Delta S$ Cabibbo-enhanced decays for $\Omega_1^{*0}, \Omega_2^{*+}, \Omega_3^{*++}$ isobars in s and u channels. The vanishing asymmetries are obtained for these decays. However, a small nonzero contribution arising from the t channel may appear.

So far we have discussed those decays where the spin-parity of the initial and final baryonic states are the same. But there are other possible charm decays such as $D(\frac{3}{2}^+)$ decaying to $B(\frac{1}{2}^+)$ baryons and mesons. With the advent of charm, new channels open up in the charm-changing mode $B(\frac{1}{2}^+) \to D(\frac{3}{2}^+) + P(0^-)$. In this case CP invariance and the s-u channel symmetry of the weak Hamiltonian cannot be applied, therefore it becomes hard to distinguish between the PV and the PC modes. But we see in the case of $B(\frac{1}{2}^+) \to B(\frac{1}{2}^+) + P(0^-)$ and $D(\frac{3}{2}^+) \to D(\frac{3}{2}^+) + P(0^-)$ that the PV decays occur only through the t channel and the PC decays acquire dominant contributions from s and u channels. We assume this result to be true here also. In SU(8) symmetry scheme, it can actually be seen that all types of PV decays of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons arise only through the t-channel contribution of the most general current ⊗ current weak Hamiltonian $(\underline{63}+\underline{720}+\underline{945}+\underline{945}^*+\underline{1232})$. Small t-channel contribution to the PC decays is understandable here also, because of the appearance of unnatural-parity mesonic states.

V. $B(\frac{1}{2}^+)\to D(\frac{3}{2}^+)+P(0^-)$

This decay channel is allowed only in $\Delta C=-1$ mode due to the energy consideration. In the following we discuss only the Cabibbo-enhanced mode in the GIM model and later include the unconventional interactions.

(i) $B(3^*)\to D(10)+P(8)$. $(H_w^{20''+84})$ amplitudes are given in Table II(a). If $\underline{20}''$ dominance is assumed, these decays occur through the s channel only. The unconventional part $(H_w^{45+45^*})$ of the weak Hamiltonian allows only the s channel to contribute. Vanishing t-channel contributions forbid the decays in PV mode in both the GIM and unconventional representations. The same result is obtained at the SU(3) level.[22]

(ii) $B(3)\to D(10)+P(3^*)$. The PV decays are forbidden due to the null t-channel contribution. The PC decays [Table II(b)] arise only through $\underline{84}$ component in s and u channels. Hence $\underline{20}''$ dominance forbids these decays totally. Inclusion of $(\underline{45}+\underline{45}^*)$ allows these decays only in the s channel, therefore the PV mode remains forbidden.[22]

(iii) $B(3)\to D(6)+P(8)$. Decay amplitudes for this mode are given in Table II(c). $\underline{20}''$ dominance forbids the u channel to contribute to these decays. In this channel $\underline{20}''$ and $\underline{84}$ give nonzero contribution in the PV mode. We expect this contribution to be small as we noticed[37] in SU(8) and $SU(8)_W$ framework that all the PV decays of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons occur through $(\underline{63}+\underline{945}+\underline{945}^*)$ part of the total weak Hamiltonian. If $\underline{20}''$ and $\underline{84}$ representations are ignored for this mode, we find that here also only π^+-emitting decays are allowed.

To conclude, we notice that the most general weak Hamiltonian forbids the charmed baryons to decay to uncharmed decuplet in the PV mode, thereby indicating null asymmetry.

VI. $D(\frac{3}{2}^+)\to B(\frac{1}{2}^+)+P(0^-)$

We notice that for $\Omega^-\to\Xi\pi$ decays only s-channel decay amplitudes obey $\Delta I=\frac{1}{2}$ rule under our assumption. Therefore, these decays may acquire $\Delta I=\frac{3}{2}$ contribution from t and u channels. The recent CERN experiment[2] supports this result where the contribution of about 25% from the $\Delta I=\frac{3}{2}$ component is observed. For $\Omega^-\to\Lambda K^-$ mode, the most general weak Hamiltonian predicts an asymmetry $\alpha(\Omega^-\to\Lambda K^-)$ to be zero,[37] which is in good agreement with the experimental value:

$$\alpha(\Omega_K^-)=0.06\pm0.14\,.$$

The decay amplitudes of Ω_1^{*0}, Ω_2^{*+}, and Ω_3^{*++} for the PV and the PC modes are displayed in Table III. From $H_w^{45+45^*}$, the decay amplitudes acquire zero contribution in the s channel. In the t channel only π^+-emitting decays are allowed. We obtain null asymmetry for charmed singlet isobar Ω_3^{*++}.

VII. VECTOR-MESONIC DECAYS

In addition to the decay channels discussed, other channels, emitting vector mesons, i.e., $B(\frac{1}{2}^+)\to B(\frac{1}{2}^+)+V(1^-)$, $B(\frac{1}{2}^+)\to D(\frac{3}{2}^+)+V(1^-)$, $D(\frac{3}{2}^+)\to D(\frac{3}{2}^+)+V(1^-)$, and $D(\frac{3}{2}^+)\to B(\frac{1}{2}^+)+V(1^-)$ are also possible in the charm-changing mode. Results for these channels can be obtained from corresponding pseudoscalar mesons replaced by vector mesons as follows:

$$\pi\to\rho,\quad K\to K^*,\quad D\to D^*,$$
$$F\to F^*,\quad \eta\to V_8,\quad \eta'\to V_{15}\,.$$

Here also the most general weak Hamiltonian predicts null asymmetry for $B(\frac{1}{2}^+)\to B(\frac{1}{2}^+)+V(1^-)$ decays of $B(3)$ since $B(3)\to B(3^*)/B(6)+V(8)$ and $B(3)\to B(8)+V(3^*)$ are forbidden in PC and PV modes, respectively. Similarly the decays leading to $D(10)$ uncharmed decuplet are forbidden in the PV mode. In the PV mode only π^+-emitting decays are allowed to occur.

VIII. SUMMARY AND CONCLUSIONS

We have observed that a simple assumption such as the absence of exotic intermediate states, etc., leads to most of the observed features of the uncharmed hadronic decays. In particular with the SU(3) weak Hamiltonian $\underline{8}+\underline{27}$ it gives experimentally well-satisfied relations such as the $\Delta I=\frac{1}{2}$ and Lee-Sugawara sum rule for the PV and the PC modes and $\Sigma_+^+=0$ and $\sqrt{2}\,\Sigma_+^+-\Sigma_0^+=\sqrt{3}\,\Lambda_-^0$ for the PV and PC modes, respectively. It allows simultaneously a $\Delta I=\frac{1}{2}$ rule violation for the Ω^- decays as required experimentally.

Encouraged by the success of the assumption in obtaining these results, we have extended our study to the weak decays of charmed hadrons in SU(4). We note that the GIM contribution vanishes for the PV weak decays. In SU(4), the PV decays of uncharmed hadrons may occur through $\underline{15}_S$ admixture, which can arise through SU(4) breaking.[17] But the PV decays of charmed baryons seem to arise through $\underline{15}_A$, $\underline{45}$, $\underline{45}^*$ antisymmetric

TABLE II. $\Delta C=\Delta S$ $(\frac{1}{2}^+ \to \frac{3}{2}^+ + 0^-)$. All the decays in parts (a) and (b) are forbidden in the t channel. NEIS=nonexotic intermediate state.

	s channel					u channel				
Hamiltonian	20″	84		45+45*		20″	84			45+45*
NEIS	20′	20′	20	20′	20	None	$20'_1$	$20'_2$	20	Not allowed
(a) $B(3^*)\to D(10)+P(8)$										
$\Lambda_1'^+ \to \Sigma^{*0}\pi^+$	$\frac{1}{6}$	$-\frac{3}{6}$	$-\frac{8}{6}$	$-\frac{2}{6}$	$-\frac{8}{6}$	0	$-\frac{4}{6}$	$-\frac{2}{6}$	$\frac{12}{6}$	0
$\to \Sigma^{*+}\pi^0$	$\frac{1}{6}$	$-\frac{3}{6}$	$-\frac{8}{6}$	$-\frac{2}{6}$	$-\frac{8}{6}$	0	$-\frac{4}{6}$	$-\frac{2}{6}$	$\frac{12}{6}$	0
$\to \Sigma^{*+}\eta$	$1/6\sqrt{3}$	$-5/6\sqrt{3}$	0	$-1/\sqrt{3}$	0	0	$4/6\sqrt{3}$	$-6/6\sqrt{3}$	0	0
$\to \Sigma^{*+}\eta'$	$1/3\sqrt{6}$	$-1/3\sqrt{6}$	$-2/\sqrt{6}$	0	$-2/\sqrt{6}$	0	$-1/3\sqrt{6}$	$-2/3\sqrt{6}$	$-6/3\sqrt{6}$	0
$\to \Xi^{*0}K^+$	$1/3\sqrt{2}$	$-1/\sqrt{2}$	$-8/3\sqrt{2}$	$-2/3\sqrt{2}$	$-8/3\sqrt{2}$	0	$-2/\sqrt{2}$	$-2/\sqrt{2}$	$2/\sqrt{2}$	0
$\to \Delta^{++}K^-$	$1/\ \sqrt{6}$	$1/\sqrt{6}$	$-4/\sqrt{6}$	$2/\sqrt{6}$	$-4/\sqrt{6}$	0	0	0	0	0
$\to \Delta^+\bar{K}^0$	$1/3\sqrt{2}$	$1/3\sqrt{2}$	$-4/3\sqrt{2}$	$2/3\sqrt{2}$	$-4/3\sqrt{2}$	0	0	0	0	0
$\Xi_1'^0 \to \Sigma^{*+}K^-$	$1/3\sqrt{2}$	$-1/3\sqrt{2}$	$-2/3\sqrt{2}$	0	$2/3\sqrt{2}$	0	0	$-6/3\sqrt{2}$	$6/3\sqrt{2}$	0
$\to \Sigma^{*0}\bar{K}^0$	$\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{2}{6}$	0	$2/6$	0	$-\frac{4}{6}$	$-\frac{2}{6}$	$\frac{8}{6}$	0
$\to \Xi^{*0}\pi^0$	$\frac{1}{6}$	$\frac{3}{6}$	$-\frac{2}{6}$	$-\frac{4}{6}$	$1/6$	0	$-\frac{4}{6}$	$\frac{8}{6}$	$\frac{6}{6}$	0
$\to \Xi^{*0}\eta$	$-1/6\sqrt{3}$	$5/6\sqrt{3}$	$2/6\sqrt{3}$	$-4/6\sqrt{3}$	$-3/6\sqrt{3}$	0	$4/6\sqrt{3}$	$-4/6\sqrt{3}$	$-18/6\sqrt{3}$	0
$\to \Xi^{*0}\eta'$	$2/6\sqrt{6}$	$2/6\sqrt{6}$	$-4/6\sqrt{6}$	0	$3/6\sqrt{6}$	0	$-2/6\sqrt{6}$	$-8/6\sqrt{6}$	0	0
$\to \Xi^{*-}\pi^+$	$1/3\sqrt{2}$	$3/3\sqrt{2}$	$-2/3\sqrt{2}$	$-4/3\sqrt{2}$	$1/3\sqrt{2}$	0	0	0	0	0
$\to \Omega^-K^+$	$1/\sqrt{6}$	$3/\sqrt{6}$	$-2/\sqrt{6}$	$-4/\sqrt{6}$	$1/\sqrt{6}$	0	0	0	0	0
$\Xi_1'^+ \to \Xi^{*0}\pi^+$	0	0	0	0	0	0	$4/3\sqrt{2}$	$-4/3\sqrt{2}$	$-6/3\sqrt{2}$	0
$\to \Sigma^{*+}\bar{K}^0$	0	0	0	0	0	0	$-4/3\sqrt{2}$	$4/3\sqrt{2}$	$6/3\sqrt{2}$	0

TABLE II. (*Continued*)

Hamiltonian	s channel 20″	s channel 84		s channel 45+45*		u channel 20″	u channel 84			u channel 45+45*
NEIS	20′	20′	20	20′	20	None	$20'_1$	$20'_2$	20	Not allowed
(b) $B(3)\to D(10)+P(3^*)$										
$\Xi_2^{++}\to\Sigma^{*+}D^+$	0	0	0	0	0	0	$-4/\sqrt{3}$	$2/\sqrt{3}$	$2/\sqrt{3}$	0
$\Xi_2^{+}\to\Sigma^{*0}D^+$	0	$-2/\sqrt{3}$	$-1/\sqrt{3}$	$2/\sqrt{3}$	$1/\sqrt{3}$	0	$-4/\sqrt{3}$	0	$4/\sqrt{3}$	0
$\to\Sigma^{*+}D^0$	0	$-2/\sqrt{3}$	$-1/\sqrt{3}$	$2/\sqrt{3}$	$1/\sqrt{3}$	0	0	$-2/\sqrt{3}$	$2/\sqrt{3}$	0
$\to\Xi^{*0}F^+$	0	$-2/\sqrt{3}$	$-1/\sqrt{3}$	$2/\sqrt{3}$	$1/\sqrt{3}$	0	0	$-2/\sqrt{3}$	$2/\sqrt{3}$	0
$\Omega_2^{+}\to\Xi^{*0}D^+$	0	0	0	0	0	0	$-4/\sqrt{3}$	$2/\sqrt{3}$	$2/\sqrt{3}$	0

Hamiltonian	t channel 20″	t channel 84	t channel 45+45*	s channel 20″	s channel 84		s channel 45+45*		u channel 20″	u channel 84			u channel 45+45*
NEIS	15	15	15	20′	20′	20	20′	20	None	$20'_1$	$20'_2$	20	Not allowed
(c) $B(3)\to D(6)+P(8)$													
$\Omega_2^{+}\to\Omega_1^{*0}\pi^+$	$-1/\sqrt{3}$	$-1/\sqrt{3}$	$2/\sqrt{3}$	0	0	0	0	0	0	0		0	0
$\to\Xi_1^{*+}\bar{K}^0$	$1/\sqrt{6}$	$-1/\sqrt{6}$	0	0	0	0	0	0	0	0	$-2/\sqrt{6}$	$-2/\sqrt{6}$	0
$\Xi_2^{+}\to\Xi_1^{*0}\pi^+$	$-1/\sqrt{6}$	$-1/\sqrt{6}$	$2/\sqrt{6}$	$1/\sqrt{6}$	$1/\sqrt{6}$	$-1/\sqrt{6}$	$-2/\sqrt{6}$	$4/\sqrt{6}$	0	0	0	0	0
$\to\Sigma_1^{*+}\bar{K}^0$	$1/\sqrt{6}$	$-1/\sqrt{6}$	0	0	0	$-1/\sqrt{6}$	0	$-4/\sqrt{6}$	0	0	0	0	0
$\to\Sigma_1^{*++}K^-$	0	0	0	$1/\sqrt{3}$	$1/\sqrt{3}$	0	0	0	0	0	0	0	0
$\to\Xi_1^{*+}\pi^0$	0	0	0	$1/2\sqrt{3}$	$1/2\sqrt{3}$	$-1/2\sqrt{3}$	$-1/\sqrt{3}$	$-1/2\sqrt{3}$	0	0	$-1/\sqrt{3}$	$2/\sqrt{3}$	0
$\to\Xi_1^{*+}\eta$	0	0	0	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$-\frac{2}{6}$	$\frac{4}{6}$	0	0	-1	$-\frac{2}{3}$	0
$\to\Omega_1^{*0}K^+$	0	0	0	$1/\sqrt{3}$	$1/\sqrt{3}$	$-1/\sqrt{3}$	$-2/\sqrt{3}$	$4/\sqrt{3}$	0	0	0	0	0
$\Xi_2^{++}\to\Sigma_1^{*++}\bar{K}^0$	$1/\sqrt{3}$	$-1/\sqrt{3}$	0	0	0	0	0	0	0	0	0	0	0
$\to\Xi_1^{+}\pi^0$	$-1/\sqrt{6}$	$-1/\sqrt{6}$	$2/\sqrt{6}$	0	0	0	0	0	0	0	0	$-4/\sqrt{6}$	0
(d) Ω_1^0 decays													
$\Omega_1^0\to\Xi^{*0}\bar{K}^0$	$1/\sqrt{3}$	$-1/\sqrt{3}$	0	0	0	0	0	0	0	$-4/\sqrt{3}$	0	0	0
$\to\Omega^-\pi^+$	-1	-1	2	0	0	0	0	0	0	0	0	0	0

TABLE III. $D(\frac{3}{2}^+) \to B(\frac{1}{2}^+) + P(0^-)$. Note: All the decays are forbidden in the s channel. NEIS=nonexotic intermediate state.

	t channel			u channel				
Hamiltonian	20″	84	45+45*	20″	84		45+45*	
NEIS	15	15	15	20′	20′	20	20′	20
$\Omega_1^{*0} \to \Xi^0 \overline{K}^0$	$-2/\sqrt{3}$	$2/\sqrt{3}$	0	$1/\sqrt{3}$	$-1/\sqrt{3}$	$-2/\sqrt{3}$	$-2/\sqrt{3}$	$-2/\sqrt{3}$
$\Omega_2^{*+} \to \Xi_1'^+ \overline{K}^0$	$-2/\sqrt{2}$	$2/\sqrt{2}$	0	$2/3\sqrt{2}$	0	$2/3\sqrt{2}$	$-2/3\sqrt{2}$	$-4/3\sqrt{2}$
$\to \Xi_1^+ \overline{K}^0$	$-2/\sqrt{6}$	$2/\sqrt{6}$	0	0	$2/\sqrt{6}$	$2/\sqrt{6}$	$-2/\sqrt{6}$	0
$\to \Omega_1^0 \pi^+$	$-2/\sqrt{3}$	$2/\sqrt{3}$	$-2/\sqrt{3}$	0	0	0	0	0
$\to \Xi^0 D^+$	0	0	0	$1/\sqrt{3}$	$-1/\sqrt{3}$	$-2/\sqrt{3}$	$-2/\sqrt{3}$	$-2/\sqrt{3}$
$\Omega_3^{*++} \to \Xi_1'^+ D^+$	0	0	0	$2/\sqrt{6}$	0	$2/\sqrt{6}$	$-2/\sqrt{6}$	$2/\sqrt{6}$
$\to \Xi_1^+ D^+$	0	0	0	0	$2/\sqrt{2}$	$2/\sqrt{2}$	$-2/\sqrt{2}$	$2/\sqrt{2}$
$\to \Xi_2^{++} \overline{K}^0$	-2	2	0	0	0	0	0	0

representations of the weak Hamiltonian. This type of structure for the PV weak Hamiltonian can be obtained through SU(4) breaking[17] or by including unconventional currents such as the right-handed current[7] and the second-class currents.[8] In this paper we have not gone into the details of the origin of these terms and have obtained the results with symmetry considerations. We notice that the PV weak decays occur predominantly through the t channel.

In the case of PC mode, we have ignored the t-channel contributions, which are expected to be small owing to the presence of unnatural-parity eigenstates, having low Regge intercept. For the GIM model, we obtain $\underline{20}''$ dominance for the PC Hamiltonian. However, $\underline{15}$ contributions are demanded by the present data on uncharmed decays. The parity-conserving Hamiltonian arising through unconventional interaction transforms like $\underline{15}_S + \underline{20}'' + \underline{84}$. The $\underline{84}$ component vanishes with our assumptions. The PC decays do not seem to get a significant contribution from unconventional currents.[7,8]

In this paper we have studied the two-body weak decays of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons in the channels $B(\frac{1}{2}^+) \to B(\frac{1}{2}^+) + P(0^-)$ $[V(1^-)]$, $B(\frac{1}{2}^+) \to D(\frac{3}{2}^+) + P(0^-)/[V(1^-)]$, $D(\frac{3}{2}^+) \to B(\frac{1}{2}^+) + P(0^-)$ $[V(1^-)]$, and $D(\frac{3}{2}^+) \to D(\frac{3}{2}^+) \to D(\frac{3}{2}^+) + P(0^-)$ $[V(1^-)]$. We find that the decay channels $B(3^*) \to D(10) + P(8)$, $B(3) \to B(8) + P(3^*)$, $B(3) \to D(10) + P(3^*)$ are forbidden in the PV mode, whereas the channels $B(3) \to B(6) + P(8)$, $B(3) \to B(3^*) + P(8)$ obtain zero contribution in the PC mode. Thus we predict null asymmetry for these channels. In the allowed channels, the most general Hamiltonian allows only π^+/ρ^+-emitting decays in $D(\frac{3}{2}^+) \to D(\frac{3}{2}^+) + P(0^-)[V(1^-)]$ and $B(\frac{1}{2}^+) \to B(\frac{1}{2}^+) + P(0^-)[V(1^-)]$ in the PV mode. This provides a good test of our model. We predict null asymmetry for Ω_3^{*++} decays also.

Finally, we conclude that although the conventional weak Hamiltonian works well for the uncharmed sector and the PC decays of charmed baryons, the PV decays of charmed baryons seem to occur through unconventional weak interactions.

ACKNOWLEDGMENTS

S. K. gratefully acknowledges the financial support given by the Council of Scientific and Industrial Research, New Delhi. M. P. K. acknowledges partial financial assistance from University Grants Commission of India. M. P. K. is thankful to A. N. Kamal for hospitality at the Department of Physics, University of Alberta. This work was also supported in part by a grant from the Natural Science and Engineering Research Council of Canada.

APPENDIX A

Following are the reduced matrix elements for the different modes.

(a) $B(\frac{1}{2}^+) \to B(\frac{1}{2}^+) + P(0^-)$

H_w^{15}:

s channel $\langle 20' || 15 || m \rangle \langle m || 15 || 20' \rangle$, $m = 4^*, 20, 20'_{11}, 20'_{12}, 20'_{21}, 20'_{22}, 36^*, 60^*, 140''$,

t channel $\langle 15 || 15 || m \rangle \langle m || 20'^* || 20' \rangle$, $m = 1, 15_{11}, 15_{12}, 15_{21}, 15_{22}, 20'', 45, 45^*, 84$,

u channel $\langle 20' || 15 || m \rangle \langle m || 15 || 20' \rangle$, $m = 4^*, 20, 20'_{11}, 20'_{12}, 20'_{21} 20'_{22}, 36^*, 60^*, 140''$;

$H_w^{20''}$:

s channel $\langle 20' || 15 || m \rangle \langle m || 20'' || 20' \rangle$, $m = 4^*, 20'_1\ 20'_2, 36^*, 60^*, 140''$,

t channel $\langle 15 || 20'' || m \rangle \langle m || 20'^* || 20' \rangle$, $m = 15_1, 15_2, 20'', 45, 45^*, 175$,

u channel $\langle 20' || 20'' || m \rangle \langle m || 15 || 20' \rangle$, $m = 4^*, 20'_1, 20'_2, 36^*, 60^*, 140''$;

H_w^{84}:

s channel $\langle 20' || 15 || m \rangle \langle m || 84 || 20' \rangle$, $m = 20, 20'_1, 20'_2, 36^*, 60^* 140''$,

t channel $\langle 15 || 84 || m \rangle \langle m || 20'^* || 20' \rangle$, $m = 15_1, 15_2, 45, 45^*, 84_1, 84_2, 175$,

u channel $\langle 20' || 84 || m \rangle \langle m || 15 || 20' \rangle$, $m = 20, 20'_1, 20'_2, 36^*, 60^*, 140''$;

H_w^{45}:

s channel $\langle 20' || 15 || m \rangle \langle m || 45 || 20' \rangle$, $m = 20, 20'_1, 20'_2, 36^*, 60^*, 140''_1, 140''_2$,

t channel $\langle 15 || 45^* || m \rangle \langle m || 20'^* || 20' \rangle$, $m = 15_1, 15_2, 20'', 45^*_1, 45^*_2, 84, 175$,

u channel $\langle 20' || 45^* || m \rangle \langle m || 15 || 20' \rangle$, $m = 4^*, 20'_1, 20'_2, 36^*_1, 36^*_2, 60^*, 140''$;

H_w^{45*}:

s channel $\langle 20' || 15 || m \rangle \langle m || 45^* || 20' \rangle$, $m = 4^*, 20'_1, 20'_2, 36^*_1, 36^*_2, 60^*, 140''$,

t channel $\langle 15 || 45 || m \rangle \langle m || 20'^* || 20' \rangle$, $m = 15_1, 15_2, 20'', 45_1, 45_2, 84, 175$,

u channel $\langle 20' || 45 || m \rangle \langle m || 15 || 20' \rangle$, $m = 20, 20'_1, 20'_2, 36^*, 60^*, 140''_1, 140''_2$;

(b) $D(\frac{3}{2}^+) \to D(\frac{3}{2}^+) + P(0^-)$

H_w^{15}:

s channel $\langle 20 || 15 || m \rangle \langle m || 15 || 20 \rangle$, $m = 20, 20', 120, 140''$,

t channel $\langle 15 || 15 || m \rangle \langle m || 20^* || 20 \rangle$, $m = 1, 15_1, 15_2, 84$,

u channel $\langle 20 || 15 || m \rangle \langle m || 15 || 20 \rangle$, $m = 20, 20', 120, 140''$;

$H_w^{20''}$:

s channel $\langle 20 || 15 || m \rangle \langle m || 20'' || 20 \rangle$, $m = 140''$,

t channel $\langle 15 || 20'' || m \rangle \langle m || 20^* || 20 \rangle$, $m = 15$,

u channel $\langle 20 || 20'' || m \rangle \langle m || 15 || 20 \rangle$, $m = 140''$;

H_w^{84}:

s channel $\langle 20 || 15 || m \rangle \langle m || 84 || 20 \rangle$, $m = 20, 20', 120, 140''$,

t channel $\langle 15 || 84 || m \rangle \langle m || 20^* || 20 \rangle$, $m = 15, 84_1, 84_2, 300$,

u channel $\langle 20 || 84 || m \rangle \langle m || 15 || 20 \rangle$, $m = 20, 20', 120, 140''$;

H_w^{45}:

s channel $\langle 20 || 15 || m \rangle \langle m || 45 || 20 \rangle$, $m = 120, 140''$,

t channel $\langle 15 || 45^* || m \rangle \langle m || 20^* || 20 \rangle$, $m = 15, 84$,

u channel $\langle 20 || 45^* || m \rangle \langle m || 15 || 20 \rangle$, $m = 20', 140''$;

H_w^{45*}:

s channel $\langle 20 || 15 || m \rangle \langle m || 45^* || 20 \rangle$, $m = 20', 140''$,

t channel $\langle 15 || 45 || m \rangle \langle m || 20^* || 20 \rangle$, $m = 15, 84$,

u channel $\langle 20 || 45 || m \rangle \langle m || 15 || 20 \rangle$, $m = 120, 140''$;

(c) $B(\frac{1}{2}^+) \to D(\frac{3}{2}^+) + P(0^-)$

H_w^{15}:

s channel $\langle 20||15||m\rangle\langle m||15||20'\rangle$, $m = 20, 20_1', 20_2', 140''$,

t channel $\langle 15||15||m\rangle\langle m||20^*||20'\rangle$, $m = 15_1, 15_2, 45^*, 84$,

u channel $\langle 20||15||m\rangle\langle m||15||20'\rangle$, $m = 20, 20_1', 20_2', 140''$;

$H_w^{20''}$:

s channel $\langle 20||15||m\rangle\langle m||20''||20'\rangle$, $m = 20', 140''$,

t channel $\langle 15||20''||m\rangle\langle m||20^*||20'\rangle$, $m = 15, 45^*$,

u channel $\langle 20||20''||m\rangle\langle m||15||20'\rangle$, $m = 36^*, 140''$;

H_w^{84}:

s channel $\langle 20||15||m\rangle\langle m||84||20'\rangle$, $m = 20, 20', 120, 140''$,

t channel $\langle 15||84||m\rangle\langle m||20^*||20'\rangle$, $m = 15, 45^*, 84_1, 84_2, 256$,

u channel $\langle 20||84||m\rangle\langle m||15||20'\rangle$, $m = 20, 20_1', 20_2', 60^*, 140''$;

H_w^{45}:

s channel $\langle 20||15||m\rangle\langle m||45||20'\rangle$, $m = 20, 20', 140_1'', 140_2'', 120$,

t channel $\langle 15||45^*||m\rangle\langle m||20^*||20'\rangle$, $m = 15, 84, 45_1^*, 45_2^*, 256$,

u channel $\langle 20||45^*||m\rangle\langle m||15||20'\rangle$, $m = 4^*, 20_1', 20_2', 36^*, 140''$;

$H_w^{45^*}$

s channel $\langle 20||15||m\rangle\langle m||45^*||20'\rangle$, $m = 20', 140''$,

t channel $\langle 15||45||m\rangle\langle m||20^*||20'\rangle$, $m = 15, 84$,

u channel $\langle 20||45||m\rangle\langle m||15||20'\rangle$, $m = 60^*, 140''$;

(d) $D(\frac{3}{2}^+) \to B(\frac{1}{2}^+) + P(0^-)$

H_w^{15}:

s channel $\langle 20'||15||m\rangle\langle m||15||20\rangle$, $m = 20, 20_1', 20_2', 140''$,

t channel $\langle 15||15||m\rangle\langle m||20'^*||20\rangle$, $m = 15_1, 15_2, 45, 84$,

u channel $\langle 20'||15||m\rangle\langle m||15||20\rangle$, $m = 20, 20_1', 20_2', 140''$;

$H_w^{20''}$:

s channel $\langle 20'||15||m\rangle\langle m||20''||20\rangle$, $m = 36^*, 140''$,

t channel $\langle 15||20''||m\rangle\langle m||20'^*||20\rangle$, $m = 15, 45$,

u channel $\langle 20'||20''||m\rangle\langle m||15||20\rangle$, $m = 20', 140''$;

H_w^{84}:

s channel $\langle 20'||15||m\rangle\langle m||84||20\rangle$, $m = 20, 20_1', 20_2', 60^*, 140''$,

t channel $\langle 15||84||m\rangle\langle m||20'^*||20\rangle$, $m = 15, 45, 84_1, 84_2, 256$,

u channel $\langle 20'||84||m\rangle\langle m||15||20\rangle$, $m = 20, 20', 120, 140''$;

H_w^{45}:

s channel $\langle 20' \| 15 \| m\rangle\langle m \| 45 \| 20\rangle$, $m = 60^*, 140''$,

t channel $\langle 15 \| 45^* \| m\rangle\langle m \| 20'^* \| 20\rangle$, $m = 15, 84$,

u channel $\langle 20' \| 45^* \| m\rangle\langle m \| 15 \| 20\rangle$, $m = 20', 140''$;

H_w^{45*}:

s channel $\langle 20' \| 15 \| m\rangle\langle m \| 45^* \| 20\rangle$, $m = 4^*, 20_1', 20_2', 36^*, 140''$,

t channel $\langle 15 \| 45 \| m\rangle\langle m \| 20'^* \| 20\rangle$, $m = 15, 45_1, 45_2, 84, 256$,

u channel $\langle 20' \| 45 \| m\rangle\langle m \| 15 \| 20\rangle$, $m = 20, 20', 140_1'', 140_2'', 120$.

APPENDIX B

For the PV decays, the representation $(6^* + 15)$ at the SU(3) level gives the following sum rules.

(*i*) $B(3^*) \to B(8) + P(8)$:

$$0 = \langle \Sigma^+\pi^0 | \Lambda_1'^+\rangle = \langle \Sigma^+\eta | \Lambda_1'^+\rangle = \langle \Sigma^0\pi^+ | \Lambda_1'^+\rangle = \langle \Xi^0 K^+ | \Lambda_1'^+\rangle$$
$$= \langle \Xi^0\pi^0 | \Xi_1'^0\rangle = \langle \Xi^0\eta | \Xi_1'^0\rangle,$$
$$\langle p\bar{K}^0 | \Lambda_1'^+\rangle = \langle \Sigma^+\bar{K}^0 | \Xi_1'^+\rangle = \sqrt{6}\,\langle \Lambda\bar{K}^0 | \Xi_1'^0\rangle = \sqrt{2}\,\langle \Sigma^0\bar{K}^0 | \Xi_1'^0\rangle,$$
$$\langle \Xi^0\pi^+ | \Xi_1'^+\rangle = -\langle \Xi^-\pi^+ | \Xi_1'^0\rangle = -\sqrt{3/2}\,\langle \Lambda\pi^+ | \Lambda_1'^+\rangle.$$

(*ii*) $B(3) \to B(8) + P(3^*)$:

$$0 = \langle \Sigma^+D^+ | \Xi_2^{++}\rangle = \langle \Lambda D^+ | \Xi_2^+\rangle = \langle \Sigma^+D^0 | \Xi_2^+\rangle = \langle \Sigma^0 D^+ | \Xi_2^+\rangle$$
$$= \langle \Xi^0 F^+ | \Xi_2^+\rangle = \langle \Xi^0 D^+ | \Omega_2^+\rangle.$$

(*iii*) $B(3) \to B(3^*) + P(8)$:

$$0 = \langle \Xi_1'^+\pi^0 | \Xi_2^+\rangle = \langle \Xi_1'^+\eta | \Xi_2^+\rangle,$$
$$\langle \Xi_1'^+\pi^+ | \Xi_2^{++}\rangle = -\langle \Xi_1'^0\pi^+ | \Xi_2^+\rangle,$$
$$\langle \Lambda_1'^+\bar{K}^0 | \Xi_2^+\rangle = -\langle \Xi_1'^+\bar{K}^0 | \Omega_2^+\rangle.$$

(*iv*) $B(3) \to B(6) + P(8)$:

$$0 = \langle \Sigma^{++}K^- | \Xi_2^+\rangle = \langle \Xi_1^+\pi^0 | \Xi_2^+\rangle = \langle \Xi_1^+\eta | \Xi_2^+\rangle = \langle \Omega_1^0 K^+ | \Xi_2^+\rangle,$$
$$-\langle \Sigma_1^{++}\bar{K}^0 | \Xi_2^{++}\rangle = \sqrt{2}\langle \Xi_1^+\pi^+ | \Xi_2^{++}\rangle = \sqrt{2}\,\langle \Xi_1^0\pi^+ | \Xi_2^+\rangle = \langle \Omega_1^0\pi^+ | \Omega_2^+\rangle,$$
$$\langle \Sigma_1^+\bar{K}^0 | \Xi_2^+\rangle = \langle \Xi_1^+\bar{K}^0 | \Omega_2^+\rangle.$$

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