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Non-leptonic weak decays of charmed baryons

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Abstract. It is shown that the $\triangle C_h = \triangle S$ decays of a baryon sextuplet, triplet and singlet of SU (3), into meson and baryon, can provide simple tests of the isospin and SU (3) transformation properties of the $\triangle C_h = \triangle S$ non-leptonic interaction in the Glashow Iliopoulos-Maiani scheme.

Keywords. Charmed baryons; non-leptonic decays; sum rules.

1. Introduction

The extremely narrow width of the new vector mesons at 3·1 GeV (Aubert *et al* 1974, Augustin *et al* 1974, Bacci *et al* 1974) and 3·7 GeV (Abrams *et al* 1974) is at present understood on the basis of a larger symmetry group, than SU(3), underlying the strong interactions of hadrons. A popular choice for the larger symmetry group is SU(4) in which the new quantum number C_h, is called 'charm' (Bjorken and Glashow 1964; De Rujula and Glashow 1975). A direct test of the underlying SU(4) would be relations between stronger interaction quantities like masses (Borchardt *et al* 1975; Gaillard *et al* 1975) and coupling constants (Gupta 1976 *a*). However, at least some of the low-lying charmed hadrons (not yet found) would be stable with respect to strong decays and will manifest themselves through their weak interaction decays. To study their weak decays one uses the weak interaction proposed by Glashow *et al* (1970) and this will be referred to as the GIM-scheme for short.

The lowest charmed mesons with charm $C_h = +1$ are expected to belong to the 3* representation of SU(3) and denoted by P (3*) for $J^P = 0^-$, etc. [We will refer to SU(3) and SU(4) representations by their dimensionality N_3 and N_4 and where necessary to avoid confusion denote them by $N_3\,(p_1, p_2)$ or $N_4\,(p_1, p_2, p_3)$ in the highest weight notation. We use the notation for multiplets, states, etc, used earlier in Gupta 1976 *a*]. The low-lying charmed baryons are expected to belong to two inequivalent twenty dimensional representations of SU(4) denoted by D(20) and B(20′) for $J^P = (3/2)^+$ and $(1/2)^+$ respectively. The SU(3) multiplets contained in B(20′) are B(8), B(6), B(3*) and B(3) with $C_h = 0, 1, 1$ and 2 respectively, while D(20) contains D(10), D(6) and D(3) and D(1) with $C_h = 0, 1, 2$ and 3. B(8) and D(10) are the usual $(1/2)^+$ octet and $(3/2)^+$ decuplet of baryons. The lowest lying baryons are expected to belong to B (3*), B (6) or D (6) as they carry the least amount of charm, namely $C_h = +1$.

However, it is not clear which of these would be stable with respect to strong interactions and electromagnetic decays. In fact, at present, in the absence of a mass scale (or the discovery of charmed hadrons) it is a moot point as to which of the charmed baryon SU(3) multiplets ($D(N_3)$ or $B(N_3)$) will decay only by weak interactions.

The non-leptonic weak decays of $B(3^*)$ and $P(3^*)$, using the GIM-scheme, have already been discussed (Altarelli *et al* 1975 *a* and 1975 *b*; Gupta 1976 *b*; Kingsley *et al* 1975; Einhorn and Quigg 1975) and one finds simple relations, between decay amplitudes satisfying $\triangle C_h = \triangle S$ rule ($S =$ strangeness), which can provide a test of the GIM-scheme. However, the relations for $B(3^*)$ decays may become useless because depending on the mass breaking interaction the lowest lying baryons may belong to B(6) or D(6) (Note the higher of the two will decay predominantly into the other electromagnetically). Further depending on spacing between the various SU(3) multiplets and the mass of $C_h = \pm 1$ mesons the lower one of B(3) or D(3) and even D(1) may be stable with respect to both strong and electromagnetic interactions and have only weak decays. Consequently in this note we discuss the following $\triangle C_h = \triangle S$ decays.

$$B(6) \rightarrow B(8) + P(9) \tag{1}$$

$$B(3) \rightarrow B(8) + P(3^*) \tag{2 a}$$

$$\rightarrow B(3^*) + P(9) \tag{2 b}$$

$$\rightarrow B(6) + P(9) \tag{2 c}$$

as well as D (1) decays at the isospin and SU(3) level and show that they can provide simple tests of the isospin and SU(3) properties of the full $\triangle C_h = \triangle S$ weak interaction in the GIM-scheme. Since our analysis is at the SU(3) level it covers all the possible $\triangle C_h = \triangle S$ decays involving D(6), D(3), B(3) and B(6) and a meson (0^-, 1^-, etc.) nonet with obvious appropriate replacements. The analysis presented here together with earlier work (Altarelli *et al* 1976; Gupta 1976 *b*; Kingsley *et al.* 1975; Einhorn and Quigg 1975) will complete the discussion of the $\triangle C_h = \triangle S$ decays of all the low lying charmed baryons one may expect to find in the future.

In section 2 we briefly discuss mass relations and the ordering of the various baryon SU(3) multiplets in broken SU(4) and SU(3) symmetry and substantiate the above remarks about the various possibilities. In section 3 the non-leptonic $\triangle C_h = \triangle S$ weak interaction in the GIM-scheme together with its transformation properties is presented. In section 4 the relations for the decays of B(6) given in (1) are given, while in section 5 we give the results for the decays of B(3) listed above. The decays of D(1) are briefly remarked upon in section 5 *d*. A summary together with concluding remarks are given in the last section.

2. Comment on ordering of baryon masses in broken SU(4) and SU(3)

In discussing mass relations one assumes that the SU(4) symmetry breaking interaction transforms like the fifteenth component of a SU(4) 15-plet (*i.e.*, like T_4^4 in tensor notation) plus the eighth component of SU(4) 15-plet (*i.e.*, like T_3^3) which is also the eighth component of the SU (3) octet in the 15-plet. The T_3^3 term gives the usual breaking of SU(3). For a meaningful discussion it is necessary to define the SU(3) and SU(4) breaking parameters a_3, b_3, c_3 and a_4, b_4 and c_4 in terms of which the masses of the various isospin multiplets in B(20′) and D(20) are given. These are defined by the mass terms

$$m^D = m_0{}^D \bar{D}^{ijk} D_{ijk} + c_3 \bar{D}^{ik3} D_{ik3} + c_4 \bar{D}^{ik4} D_{ik4}, \tag{3}$$

and

$$m^B = m_0{}^B \bar{B}^{ijk} B_{ijk} + a_3 \bar{B}^{ik3} B_{ik3} + b_3 \bar{B}^{i3k} B_{i3k} + a_4 \bar{B}^{ik4} B_{ik4} + b_4 \bar{B}^{i4k} B_{i4k}, \tag{4}$$

for the B(20′) and D(20) which are described by the tensors B_{ijk} and D_{ijk} respectively (Gupta 1976 *a*). In this definition $m_0{}^D = m_{N^*} = 1 \cdot 232$ GeV and $m_0{}^B = m_N = 0 \cdot 94$ GeV and do not represent the average masses of the D(20) and B(20′). This definition of the parameters a_3, etc. is convenient for discussing the ordering cf the masses as most of the parameters turn out to be positive. From the known masses one has $c_3 = 0 \cdot 45$ GeV, $a_3 = 0 \cdot 19$ GeV and $b_3 = 0 \cdot 23$ GeV.

Our discussion will be based on first order breaking and linear mass formula for the baryons and we also neglect the small mixing between B(3*) and B(6) due to SU(3) breaking (Borchardt *et al* 1975, Gaillard *et al* 1975). Denote the masses of the SU(3) multiplet B(N_3) and D(N_3) by m^B (N_3) and m^D (N_3) respectively. Since one has to have $m^D(6) > m^D(10)$ so that $c_4 > 0$ and one has the unique ordering

$$m^D(1) > m^D(3) > m^D(6) \tag{5}$$

for D(20) in which mass increases with charm. In case of B(20′) since $m^B(3^*) > m^B(8)$ one has $b_4 > 0$ however a_4 could be negative but its magnitude is limited by $4 \mid a_4 \mid < b_4$ because one expects $m^B(6) > m^B(8)$. This gives the unique ordering.

$$m^B(3) > m^B(3^*) > m^B(6).$$

For $a_4 > 0$ three cases arise depending on the relative magnitudes of a_4 and b_4. One finds the unique orderings.

$$m^B(6) \geqslant m^B(3) > m^B(3^*), \quad \text{if} \quad a_4 \geqslant 2b_4; \tag{6 a}$$

$$m^B(3) > m^B(6) > m^B(3^*), \quad \text{if} \quad a_4 < 2b_4,\ b_4 < 2a_4; \tag{6 b}$$

$$m^B(3) > m^B(3^*) \geqslant m^B(6), \quad \text{if} \quad b_4 \geqslant 2a_4. \tag{6 c}$$

In the literature (Borchardt *et al* 1975; Gaillard *et al* 1975) a further assumption is made that the two terms transforming like $T_3{}^3$ and $T_4{}^4$ in the symmetry breaking interaction belong to the same representation. This would imply $a_4/a_3 = b_4/b_3 = y^B$. Though $c_4/c_3 = y^D$ need not be equal to y^B, in general, it is further assumed that $y^B = y^D = y$; so that knowledge of the only one parameter fixes all the masses in B(20′) and D(20). Since one expects SU(4) to be much more badly broken than SU(3) one expects y to be much larger unity. Note since $b_3 \simeq 1 \cdot 2\, a_3$ therefore for any y the ordering of the masses of the SU(3) multiplets is given by eq. (6 *b*). With a linear mass formula we find

$$m^D(1) > m^B(3) > m^D(3) > m^B(6) \geqslant m^D(6) > m^B(3^*), \; 3\cdot4 \leqslant y < 11\cdot8 \quad (7a)$$

and

$$m^D(1) > m^B(3) > m^D(3) > m^B(6) > m^B(3^*) \geqslant m^D(6), \; y \geqslant 11\cdot8. \quad (7b)$$

Using the P(3*) masses ($\sim 2\cdot17$ and $2\cdot22$ GeV) predicted by Borchardt *et al* (1975) one finds that for $3\cdot4 \leqslant y \leqslant 13$ D(3) and for $11\cdot8 \leqslant y \leqslant 13$ D(6) would be stable with respect to strong and electromagnetic decays. It is very interesting to note that in the above range $3\cdot4 \leqslant y \leqslant 13$ even D(1) with $C_h = 3$ (analogue in SU(4) of the Ω^- in SU(3)) turns out to be stable with respect to decay by strong interactions*. To illustrate these remarks the predicted masses for the isospin multiplets $D(N_3, I)$, etc. in D(20) and B(20′) for $y = 10$ and 12 are given in table 1.

To sum up, it is clear that even in the above one parameter model for masses and more so with more parameters (a_4, b_4, etc.), there is a case for studying the weak decays of a charmed baryon sextuplet, triplet and singlet of SU(3), in addition to those of B(3*) which have already been considered.

3. The non-leptonic $\triangle C_h = \triangle S$ interaction

The hadronic weak current in the GIM-scheme (suppressing space-time structure) is given by

$$J_h = \cos\theta J_2^1 + \sin\theta J_3^1 + \cos\theta J_3^4 - \sin\theta J_2^4, \quad (8)$$

Table 1. Predicted masses (in GeV) of charmed baryon isospin, I, multiplets, in the one parameter model, in the B(20′) and D(20). The masses of $D(N_3, I)$ and $B(N_3, I)$ are denoted by $m^D(N_3, I)$ and $m^B(N_3, I)$ respectively.

y	10	12	y	10	12
$m^B(6, 1)$	3·44	3·94	$m^D(6, 1)$	2·73	3·03
$m^B(6, \frac{1}{2})$	3·63	4·13	$m^D(6, \frac{1}{2})$	2·88	3·18
$m^B(6, 0)$	3·82	4·32	$m^D(6, 0)$	3·03	3·33
$m^B(3^*, \frac{1}{2})$	2·89	3·24	$m^D(3, \frac{1}{2})$	4·23	4·83
$m^B(3^*, 0)$	2·69	3·04	$m^D(3, 0)$	4·38	4·98
$m^B(3, \frac{1}{2})$	4·80	5·56	$m^D(1, 0)$	5·73	6·63
$m^B(3, 0)$	5·05	5·81	...	..	..

* Note with a larger $y = 20$, the value determined for the vector mesons, (Borchardt *et al* 1975) and a linear mass formula *all* the charmed baryons in B(20′) and D(20) will decay by strong interactions, in which case the coupling constant sum rules for (DBP)-couplings (Gupta 1976*a*) would provide a rich testing ground of the underlying SU(4) symmetry. In such a case only the members of the P(3*) will decay by weak interactions and provide a test of H_{CS}.

where θ is the Cabibbo angle and the indices indicate the transformation properties under SU(4), etc. J_h belongs to the fifteen dimensional representation of SU(4). J_2^1 and J_3^1 are the usual $\triangle S = 0$ and $\triangle S = 1$ terms with $\triangle C_h = 0$. The terms J_3^4 and J_2^4 satisfy the selection rules $\triangle C_h = \triangle S = 1$ and $\triangle C_h = 1$, $\triangle S = 0$ respectively, where S is strangeness. The non-leptonic interaction is given by the anti-commutator $\{J_h, J_h^\dagger\}$ so that the leading charm changing term (since θ is small) is

$$H_{CS} = \cos^2\theta\, \{J_2^1, J_4^3\} + \text{h.c.} \tag{9}$$

and satisfies the $\triangle C_h = \triangle S = \pm 1$ rule. Further, H_{CS} satisfies a pure $|\triangle \boldsymbol{I}| = 1$ isospin selection rule. To see its SU(3) and SU(4) transformation properties, we write

$$H_{CS} = H_- + H_+, \tag{10}$$

$$H_\pm = \tfrac{1}{2}\cos^2\theta\, [\{J_2^1, J_4^3\} \pm \{J_2^3, J_4^1\}] + \text{h.c.} \tag{11}$$

Clearly both H_+ and H_- satisfy a pure $|\triangle \boldsymbol{I}| = 1$ rule. It is easy to see that (i) H_- transforms as $(\underline{6} + \underline{6}^*)$ under SU(3) and as the self-conjugate twenty dimensional representation (0, 2, 0), denoted by $\underline{20}''$, under SU(4); (ii) H_+ transforms as $(\underline{15} + \underline{15}^*)$ under SU(3) and belongs to the 84 dimensional representations (2, 0, 2) of SU (4). The fifteen dimensional representation of SU(3) which enters in H_+ is (2,1) and its conjugate (1, 2) and will be denoted by simply $\underline{15}$ and $\underline{15}^*$.

The SU(4) symmetry of the leading terms at short distances (Gaillard and Lee 1974; Altarelli and Maiani 1974) suggests that the SU(4) representation $\underline{20}''$ (*i.e.*, H_-) is enhanced relative to the $\underline{84}$ *i.e.*, H_+. The consequences of $\underline{20}''$-dominance have already been considered for the $\triangle C_h = \triangle S$ decays of B(3*) → B(8) + P (8) and P (3*) → P (8) + P (8) (Gaillard *et al* 1975; Altarelli *et al* 1975 *a* and 1975 *b*). In particular Altarelli *et al* 1975 *a* find that $\underline{20}''$-dominance in the SU(4) limit, gives an extra relation for the *S*-wave decays of the hyperons, namely $S(\Xi_-^-) = 2S(\Lambda_-^0)$, which is violated by about 50%, which is not too bad. Further it has been shown that the use of the full H_{CS} at the isospin and SU(3) level only gives simple relations for the B(3*) and P(3*) decays which would provide tests of the presence of both the pieces H_- and H_+ in H_{CS} (Gupta 1976 *b*). Consequently we consider the $\triangle C_h = \triangle S$ decays of B(6) and B(3) and D(1) due to H_{CS} only at the isospin and SU(3) level and present amplitude relations which arise from

(i) The $|\triangle \boldsymbol{I}| = 1$ selection rule obeyed by the full H_{CS}

(ii) The hypothesis that H_- is enhanced relative to H_+ at the SU(3) level, *i.e.*, H_{CS} transforms as $(\underline{6} + \underline{6}^*)$ at the SU(3) level. This follows from $\underline{20}''$-dominance but is weaker than that since one does not use SU(4), which would have, for example, related the B(6) and B(3) decay amplitudes and which is not the case for the H_--enhancement hypothesis at the SU(3) level.

(iii) The full H_{CS} at the SU(3) level. In this case unlike for the H_{-}-enhancement hypothesis in (ii), owing to the large number of parameters at the SU(3) level, most of the relations between decay amplitudes are not simple. Consequently we give only relations involving at most 4 or 5 decay amplitudes since they would be easier to check experimentally.

An advantage of the relations obtained from H_{CS} at the isosopin and SU(3) level is that they are valid for both the parity violating and the parity conserving amplitudes.

4. B(6) $\rightarrow$ B(8) + P(9) decays

For the charmed baryons we will use the notation $B^{Q}(N_3, I)$ where N_3 denotes its SU(3) representation, I its isospin and its charge Q will indicate its I_3-value. The 30 decay amplitudes $B_1, \ldots B_{30}$ which satisfy $\triangle C_h = \triangle S$ are defined in table 2. The physical states in the SU(3) nonet P(9) are given by (mixing angle θ_P)

$$\eta = \sin\theta_P P_1 - \cos\theta_P P_8, \tag{12 a}$$

$$\eta' = \cos\theta_P P_1 + \sin\theta_P P_8, \tag{12 b}$$

where P_1 is a pure SU(3) singlet which mixes with P_8 the eighth component of

Table 2. The 30 $\triangle C_h = \triangle S$ decay amplitudes for B(6) $\rightarrow$ B(8) + P(9). The eight primed amplitudes B_6', etc. are also defined as the amplitude relations are more compactly given in terms of them.

$B_1 = A(B^{++}(6,1) \rightarrow \pi^+ \Sigma^+)$	$B_{20} = A(B^0(6,\frac{1}{2}) \rightarrow K^- \Sigma^+)$
$B_2 = A(B^+(6,1) \rightarrow \bar{K}^0 p)$	$B_{21} = A(B^0(6,\frac{1}{2}) \rightarrow \pi^+ \Xi^-)$
$B_3 = A(B^+(6,1) \rightarrow K^+ \Xi^0)$	$B_{22} = A(B^0(6,\frac{1}{2}) \rightarrow \bar{K}^0 \Sigma^0)$
$B_4 = A(B^+(6,1) \rightarrow \pi^+ \Sigma^\circ)$	$B_{23} = A(B^0(6,\frac{1}{2}) \rightarrow \bar{K}^0 \Lambda)$
$B_5 = A(B^+(6,1) \rightarrow \pi^+ \Lambda)$	$B_{24} = A(B^0(6,\frac{1}{2}) \rightarrow \pi^0 \Xi^0)$
$B_6 = A(B^+(6,1) \rightarrow \eta\Sigma^+)$	$B_{25} = A(B^0(6,\frac{1}{2}) \rightarrow \eta\Xi^0)$
$B_7 = A(B^+(6,1) \rightarrow \pi^0 \Sigma^+)$	$B_{26} = A(B^0(6,0) \rightarrow \bar{K}^0 \Xi^0)$
$B_8 = A(B^0(6,1) \rightarrow \pi^0 \Lambda)$	$B_{27} = A(B^+(6,1) \rightarrow \eta' \Sigma^+)$
$B_9 = A(B^0(6,1) \rightarrow \pi^0 \Sigma^0)$	$B_{28} = A(B^0(6,1) \rightarrow \eta' \Lambda)$
$B_{10} = A(B^0(6,1) \rightarrow \eta \Lambda)$	$B_{29} = A(B^0(6,1) \rightarrow \eta' \Sigma^0)$
$B_{11} = A(B^0(6,1) \rightarrow \eta\Sigma^0)$	$B_{30} = A(B^0(6,1) \rightarrow \eta' \Xi^0)$
$B_{12} = A(B^0(6,1) \rightarrow \pi^- \Sigma^+)$	$B_6' = A(B^+(6,1) \rightarrow P_8 \Sigma^+)$
$B_{13} = A(B^0(6,1) \rightarrow \pi^+ \Sigma^-)$	$B'_{10} = A(B^0(6,1) \rightarrow P_8 \Lambda)$
$B_{14} = A(B^0(6,1) \rightarrow K^0 \Xi^0)$	$B'_{11} = A(B^0(6,1) \rightarrow P_8 \Sigma^0)$
$B_{15} = A(B^0(6,1) \rightarrow \bar{K}^0 n)$	$B'_{25} = A(B^0(6,\frac{1}{2}) \rightarrow P_8 \Xi^0)$
$B_{16} = A(B^0(6,1) \rightarrow K^+ \Xi^-)$	$B'_{27} = A(B^+(6,1) \rightarrow P_1 \Sigma^+)$
$B_{17} = A(B^0(6,1) \rightarrow K^- p^-)$	$B'_{28} = A(B^0(6,1) \rightarrow P_1 \Lambda)$
$B_{18} = A(B^+(6,\frac{1}{2}) \rightarrow \bar{K}^0 \Sigma^+)$	$B'_{29} = A(B^0(6,1) \rightarrow P_1 \Sigma^0)$
$B_{19} = A(B^+(6,\frac{1}{2}) \rightarrow \pi^+ \Xi^0)$	$B'_{30} = A(B^0(6,1) \rightarrow P_1 \Xi^0)$

the octet. It is convenient to define the eight primed amplitudes B_6, etc., also given in table 2, which can be expressed in terms of the corresponding unprimed ones using equations (12 *a*) and (12 *b*).

The decay amplitudes B_i will depend on eight parameters (or unknown amplitudes) which can be counted by considering $\text{B}(6) + H_\pm \to \text{B}(8) + \text{P}(9)$ and treating $H_\pm$ as spurious. The $\underline{6}^*$ part of H_- having $C_h = -1$ contributes giving three amplitudes $g_{27} = (27 \to 27\,(\text{BP}))$, $g_S(8 \to 8_S(\text{BP}))$ and $g_A(8 \to 8_A\,(\text{BP}))$, where $8_S(\text{BP})$ means the symmetric and $8_A(BP)$ the antisymmetric octet formed out of B(8) and P(8), etc. Similarly the $\underline{15}$ part of H_+ only contributes and gives rise to five amplitudes namely, $g'_{27} = (27 \to 27(\text{BP}))$, $g'_{10} = (10 \to 10\,(\text{BP}))$, $g'_{\bar{10}} = (10^* \to 10^*\,(\text{BP}))$ and $g'_{S,A} = (8 \to 8_{S,A}\,(\text{BP}))$. One obtains eight $|\triangle I| = 1$ sum rules namely

$$B_5 = B_8,\ B_6 = B_{11};\ B_{27} = B_{29}; \tag{12}$$

$$B_1 = B_4 + B_7 = 2B_9 + B_{12} + B_{13}; \tag{13 a}$$

$$B_4 - B_7 = B_{12} - B_{13}; \tag{13 b}$$

$$B_{18} = B_{20} + (\sqrt{2})\,B_{22}, \tag{14 a}$$

$$B_{19} = B_{21} + (\sqrt{2})\,B_{24}; \tag{14 b}$$

which are true for the full H_{CS}. On the H_--enhancement hypothesis only g_{27}, g_S and g_A are non-zero and one obtains 19 SU(3) sum rules. These are

$$-(\sqrt{2})\,B_2 = B_4 + (\sqrt{3})\,B_5; \tag{15 a}$$

$$-(\sqrt{2})\,B_3 = B_7 + (\sqrt{3})\,B_5,\ B_6' = B_5; \tag{15 b}$$

$$B_{12} = -B_{14},\ B_{13} = -B_{15},\ B_{16} = B_{17}; \tag{16 a}$$

$$\frac{1}{20}B_1 = -B_{16} = B_9 + (\sqrt{3})\,B_8 = B'_{10} + \frac{1}{\sqrt{3}}B_8 \tag{16 b}$$

$$-(\sqrt{6})\,B'_{25} = B_{19} - B_{21} + 2B_{20} \tag{17 a}$$

$$-(\sqrt{6})\,B_{23} = B_{18} + 2B_{21} - B_{20} \tag{17 b}$$

$$B_{18} = B_{19},\ B_3 = B_{20},\ B_2 = B_{21},\ B_1 = B_{26} = -(\sqrt{2})\,B_{18} \tag{18}$$

$$B'_{27} = -(\sqrt{3})\,B'_{28} = -B'_{30} = (\sqrt{2})\,B_8 - 2\,(\sqrt{6})\,B_{16}\,. \tag{19}$$

For the full H_{CS} though there are 14 SU(3) sum rules only two are relatively simple, namely

$$-(B_1 + B_{26}) = 2\,(B_{18} + B_{19}) = 20\,(B_{16} + B_{17}). \tag{20}$$

These can provide a test of the specific SU(3) transformation property of the ful H_{CS}.

5. B(3) and D(1) decays

There are three types of decays of B(3), at the SU(3) level, as given in (2 *a*), (2 *b*) and (2 *c*). The 24 decay amplitudes, C_i, for the various decays are defined in table 3. In addition the four primed amplitudes C'_{10}, etc., are also defined in table 3 for convenience. We give the sum rules for the three types of decays under their subheads. The decays of D(1) are given in section 5 *d*.

Table 3. The B(3) decay amplitudes satisfying $\triangle C_h = \triangle S$ selection rule

B (3) → B (8) + P (3*)	B (3) → B (6) + P (9)
$C_1 = A(B^{++}(3, \frac{1}{2}) \to D^+ \Sigma^+)$	$C_{14} = A(B^{++}(3, \frac{1}{2}) \to B^{++}(6, 1)\bar{K}^0)$
$C_2 = A(B^+(3, \frac{1}{2}) \to D^0 \Sigma^+)$	$C_{15} = A(B^{++}(3, \frac{1}{2}) \to B^+(6, \frac{1}{2})\pi^+)$
$C_3 = A(B^+(3, \frac{1}{2}) \to D^+ \Sigma^0)$	$C_{16} = A(B^+(3, \frac{1}{2}) \to B^{++}(6, 1)K^-)$
$C_4 = A(B^+(3, \frac{1}{2}) \to D^+ \Lambda)$	$C_{17} = A(B^+(3, \frac{1}{2}) \to B^+(6, 1)\bar{K}^0)$
$C_5 = A(B^+(3, \frac{1}{2}) \to F^+ \Xi^0)$	$C_{18} = A(B^+(3, \frac{1}{2}) \to B^0(6, \frac{1}{2})\pi^+)$
$C_6 = A(B^+(3, 0) \to D^+ \Xi^0)$	$C_{19} = A(B^+(3, \frac{1}{2}) \to B^+(6, \frac{1}{2})\pi^0)$
B (3) → B (3*) + P (9)	$C_{20} = A(B^+(3, \frac{1}{2}) \to B^+(6, \frac{1}{2})\eta)$
$C_7 = A(B^{++}(3, \frac{1}{2}) \to B^+(3^*, \frac{1}{2})\pi^+)$	$C_{21} = A(B^+(3, \frac{1}{2}) \to B^0(6, 0)K^+)$
$C_8 = A(B^+(3, \frac{1}{2}) \to B^0(3^*, \frac{1}{2})\pi^+)$	$C_{22} = A(B^+(3, 0) \to B^+(6, \frac{1}{2})\bar{K}^0)$
$C_9 = A(B^+(3, \frac{1}{2}) \to B^+(3^*, \frac{1}{2})\pi^0)$	$C_{23} = A(B^+(3, 0) \to B^0(6, 0)\pi^+)$
$C_{10} = A(B^+(3, \frac{1}{2}) \to B^+(3^*, \frac{1}{2})\eta)$	$C_{24} = A(B^+(3, \frac{1}{2}) \to B^+(6, \frac{1}{2})\eta')$
$C_{11} = A(B^+(3, \frac{1}{2}) \to B^+(3^*, 0)\bar{K}^0)$	$C'_{20} = A(B^+(3, \frac{1}{2}) \to B^+(6, \frac{1}{2})P_8)$
$C_{12} = A(B^+(3, 0) \to B^+(3^*, \frac{1}{2})\bar{K}^0)$	$C'_{24} = A(B^+(3, \frac{1}{2}) \to B^+(6, \frac{1}{2})P_1)$
$C_3 = A(B^+(3, \frac{1}{2}) \to B^+(3^*, \frac{1}{2})\eta')$	
$C_{10} = A(B^+(3, \frac{1}{2}) \to B^+(3^*, \frac{1}{2})P_8)$	
$C'_{13} = A(B^+(3, \frac{1}{2}) \to B^+(3^*, \frac{1}{2})P_1)$	

5 *a*. B(3) → B(3*) + P(9) *decays*

The seven decay amplitudes C_7 to C_{13} are given in terms of four parameters, two of which arise from the $\underline{6}^*$ part of H_- and two from the $\underline{15}$ part of H_+. There is only one $|\triangle I| = 1$ sum rule

$$C_7 = C_8 + (\sqrt{2})\, C_9. \tag{21}$$

With the H_--enhancement hypothesis one expects four SU(3) sum rules:

$$C_7 = -C_{12},\; C_8 = C_{11},\; C_9 = -(\sqrt{3})\, C'_{10} \tag{22}$$

$$C_8 = \tfrac{1}{4} C_7 + (\sqrt{3})\, C'_{13}. \tag{23}$$

For the full H_{CS} one expects two SU(3) sum rules, however each involves six amplitudes and consequently we omit them as they would be hard to verify.

5 *b*. B(3) → B(8) + P(3*) *decays*

In this case there are only six decay amplitudes C_1 to C_6 as the baryons do not form a nonet unlike the mesons. The sum rules in this can be obtained from (21) and (22) by replacing C_7, C_8, C_{12} by C_1, C_2 ... C_6. There is no sum rule corresponding to (23) as there is no amplitude corresponding to C'_{13} in this case. Again these decays do not provide a simple amplitude relation to test the SU(3) transformation properties of the full H_{CS}.

5 *c*. B(3) → B(6) + P(9) *decays*

The 11 decay amplitudes C_{14} to C_{21} in this case are given in terms of five parameters at the SU(3) level. Two of these come from the 6* part of H_- and three from the 15 part of H_+. One obtains two $|\triangle I| = 1$ sum rules, namely

$$C_{14} = C_{16} + (\sqrt{2})\, C_{17} \tag{24 a}$$

$$C_{15} = C_{18} + (\sqrt{2})\, C_{19}. \tag{24 b}$$

As tests of the H_- -enhancement hypothesis one obtains the following seven SU(3) sum rules:

$$C_{16} = C_{21} = 2C_{19} = (2/\sqrt{3})\, C_{20},\ C'_{24} = 0 \tag{25 a}$$

$$C_{14} = C_{23},\ C_{15} = C_{22},\ C_{17} = C_{18}, \tag{25 b}$$

Note C'_{24} is no longer zero for the full H_{CS}. For the full H_{CS} the only simpl. checkable relation which emerges, out of four SU(3) sum rules, is

$$C_{16} + C_{21} = C_{19} + (\sqrt{3})\, C'_{20}. \tag{26}$$

Thus the decays of baryon triplet can provide a test of the SU(3) transformation properties of the full H_{CS}.

5 *d*. D(1) *decays*

It was noted in section 2 that the triply charmed, doubly charged, $I = 0$, $S = 0$e SU(3) singlet state $D^{++}(1, 0)$ or D(1) may turn out to have only weak decays, Its $\triangle C_h = \triangle S$ decay amplitudes are

$$D_1 = A(D^{++}(1, 0) \to B^{++}(3, \tfrac{1}{2})\, \bar{K}^0),\ D_2 = A(D^{++}(1, 0) \to B^+(3, 0)\, \pi^+) \tag{27 a}$$

$$D_3 = A(D^{++}(1, 0) \to B^+(3^*, \tfrac{1}{2})\, D^+),\ D_4 = A(D^{++}(1, 0) \to B^+(6, \tfrac{1}{2})\, D^+). \tag{27 b}$$

Note our remarks can be applied to decays with B(3) and B(6) replaced by D(3) and D(6), if energetically allowed. The only interesting relations in this case are obtained for H_- dominance hypothesis and these are

$$D_1 = D_2;\ D_4 = 0. \tag{28}$$

6. Summary and concluding remarks

On the basis of first order breaking of SU (4) and a linear mass formula, with one parameter, we have argued that one may expect stable (except for weak interaction decays) charmed $(1/2)^+$ and $(3/2)^+$ baryons belonging to the representations 1, 3*, 3 and 6 of SU(3). Since these would decay only by weak interactions, we have studied their non-leptonic decays which satisfy the $\triangle C_h = \triangle S$ rule since these are the dominant non-leptonic decays in the GIM-scheme. In particular we have analysed the $\triangle C_h = \triangle S$ decays of a baryon, 3, 6 and 1 into baryon and meson, from the point of view of providing tests of the isospin and SU(3) transformation properties of the $\triangle C_h = \triangle S$ interaction, H_{CS}, in the GIM-scheme. We have shown that a number of simple relations can be obtained which, in future can provide tests of the full H_{CS}. As pointed earlier, our analysis is at the SU(2) and SU(3) level and as such is valid for the type of decays shown in (1) and (2) for all possible decays involving D(3), D(6), B(3), B(6), B(8) and a meson nonet be it 0^-, 1^-, etc., (*e.g.*, D(3) → B(3*) + V (9)) with appropriate replacements. Furthermore, in each case, all the amplitude relations obtained are (i) valid for the parity violating and parity conserving amplitudes; (ii) independent of whether the current J_h is pure (V–A) or not and (iii) independent of the addition of a (V + A) piece transforming like J_2^4 (De Rujula *et al* 1975) as this does not affect the $\triangle C_h = \triangle S$ non-leptonic decays.

The fascinating possibility (on the basis of mass formula in section 2) that D (1) with $C_h = 3$ (analogue of Ω^- in SU (3)) may turn out to be stable, with respect to strong and electromagnetic decays, has been remarked upon and a brief discussion of its weak decays has been included.

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