Comments on "Analysis of Two-Body Decays of Charmed Baryons Using the Quark-Diagram Scheme"

Yoji Kohara
Nihon University at Shonan, Fujisawa, Kanagawa 252, Japan

Abstract

It is proved that the nonleptonic decay amplitudes of antitriplet charmed baryons to octet baryons do not depend on the representation of the octet baryons in the quark diagram scheme. Relations among various representations are derived, and correct decay amplitudes of the charmed baryons are given.

PACS numbers: 12.15.Ji, 12.39.-x, 13.30.-a, 13.30.Eg,
The quark diagram scheme was applied to the two-body nonleptonic decays of charmed baryons in Ref. [1] and Ref. [2]. The wave functions of SU(3) octet baryons can be represented in some different forms. However, the physics is independent of the convention one chooses. In this paper it will be proved that both schemes are equivalent.

We consider only the decays of antitriplet charmed baryons to an octet baryon and a nonet pseudoscalar meson here. The octet baryon states can be represented in terms of the quark states that are antisymmetric in the first and the second quarks.

\[
|\psi_{k}(8)_{A12}\rangle = \eta_{k} \left| [q_{a}q_{b}]q_{c} \right\rangle \quad \text{for } k = p, n, \Sigma^{+}, \Sigma^{-}, \Xi^{0}, \Xi^{-},
\]

\[
|\psi_{\Sigma^{0}}(8)_{A12}\rangle = \frac{1}{\sqrt{2}} \left| [sd]u \right\rangle + \frac{1}{\sqrt{2}} \left| [su]d \right\rangle,
\]

\[
|\psi_{\Lambda}(8)_{A12}\rangle = -\frac{1}{\sqrt{6}} \left| [sd]u \right\rangle + \frac{1}{\sqrt{6}} \left| [su]d \right\rangle + \frac{2}{\sqrt{6}} \left| [du]s \right\rangle,
\]

where

\[
\left| [q_{a}q_{b}]q_{c} \right\rangle = \frac{1}{\sqrt{2}} \left( \left| q_{a}q_{b}q_{c} \right\rangle - \left| q_{b}q_{a}q_{c} \right\rangle \right),
\]

and \(\eta_{k}\) is a phase factor which depends on the convention. The octet baryon states can be represented also by antisymmetrizing the second and the third quarks.

\[
|\psi_{k}(8)_{A23}\rangle = \eta_{k} \left| q_{a}[q_{a}q_{b}] \right\rangle \quad \text{for } k = p, n, \Sigma^{+}, \Sigma^{-}, \Xi^{0}, \Xi^{-},
\]

\[
|\psi_{\Sigma^{0}}(8)_{A23}\rangle = \frac{1}{\sqrt{2}} \left| u[sd] \right\rangle + \frac{1}{\sqrt{2}} \left| d[su] \right\rangle,
\]

\[
|\psi_{\Lambda}(8)_{A23}\rangle = -\frac{1}{\sqrt{6}} \left| u[sd] \right\rangle + \frac{1}{\sqrt{6}} \left| d[su] \right\rangle + \frac{2}{\sqrt{6}} \left| s[du] \right\rangle,
\]

where

\[
\left| q_{a}[q_{b}q_{c}] \right\rangle = \frac{1}{\sqrt{2}} \left( \left| q_{a}q_{b}q_{c} \right\rangle - \left| q_{a}q_{c}q_{b} \right\rangle \right).
\]

Similarly, there are also the representations \(|\psi_{k}(8)_{A31}\rangle\) that are antisymmetric in the first and the third quarks. As we are considering only octet states, the following relation holds among quark antisymmetric states:

\[
\left| [q_{a}q_{b}]q_{c} \right\rangle + \left| q_{c}[q_{a}q_{b}] \right\rangle + \left| [q_{b}q_{c}q_{a}] \right\rangle = 0,
\]
where
\[ |[q_b q_c q_a]⟩ = \frac{1}{\sqrt{2}}([q_b q_c q_a] - [q_a q_c q_b]). \] (10)

This relation results from that the left hand side is totally antisymmetric. Because of this equation two of three terms are independent. We take the first and the second terms as independent bases. Other relations are also derived from the condition of octet states.

\[ |[q_a q_b q_c]⟩ + |[q_b q_c q_a]⟩ + |[q_c q_a q_b]⟩ = 0, \] (11)
\[ |q_a[q_b q_c]⟩ + |q_b[q_c q_a]⟩ + |q_c[q_a q_b]⟩ = 0. \] (12)

Then the states \([q_a q_b q_c]⟩\) and \([q_c[q_a q_b]⟩\) constitute a complete set for octet state space under the above eqs. (11) and (12), though they are not orthogonal. However, it is not essential in our issue whether the bases are orthogonal or not. The antisymmetric octet baryon states \(|ψ^k(8)_{A12}\rangle\) and \(|ψ^k(8)_{A23}\rangle\) can be represented in terms of quark antisymmetric states \([q_A[q_B[q_C]]⟩\) and \([q_A[q_B[q_C]]⟩\), respectively.

\[ |ψ^k(8)_{A12}\rangle = \sum_{q_a,q_b,q_c} |[q_a q_b q_c]⟩ \langle [q_a q_b q_c] |ψ^k(8)_{A12}\rangle, \] (13)
\[ |ψ^k(8)_{A23}\rangle = \sum_{q_a,q_b,q_c} |q_c[q_a q_b]⟩ \langle q_c[q_a q_b] |ψ^k(8)_{A23}\rangle. \] (14)

These equations do not depend on whether the bases are orthogonal or not. Most generally, the octet baryon states \(|B^k(8)⟩\) can be written as a combination of \(|ψ^k(8)_{A12}\rangle\) and \(|ψ^k(8)_{A23}\rangle\)

\[ |B^k(8)⟩ = α |ψ^k(8)_{A12}\rangle + β |ψ^k(8)_{A23}\rangle. \] (15)

We suppressed spin wave functions for simplicity. This equation corresponds to the following equation of Ref. [2]

\[ |B^k(8)⟩ = a |ψ^k(8)_{A}\rangle + b |ψ^k(8)_{S}\rangle, \] (16)

where \(|ψ^k(8)_{S}\rangle\) and \(|ψ^k(8)_{A}\rangle\) denote the octet baryon states that are symmetric and antisymmetric in the first two quarks, respectively. The precise values of α and β are not important in our issue.
The decay amplitudes of the antitriplet charmed baryon $B_{c}^{0}(8)$ to an octet baryon $B^{k_{0}}(8)$ and an octet pseudoscalar meson $M^{j_{0}}(8)$ are given as follows:

$$A(i_{0} \to j_{0} k_{0}) = \langle B_{c}^{0} \mid \hat{H}_{W} \mid M^{j_{0}}(8) \rangle \mid B^{k_{0}}(8) \rangle$$

$$= \langle B_{c}^{0} \mid \hat{H}_{W} \mid M^{j_{0}}(8) \rangle \left( \alpha \mid \psi^{k_{0}}(8)_{A12} \rangle + \beta \mid \psi^{k_{0}}(8)_{A23} \rangle \right)$$

$$= \sum q_{i} \alpha \langle B_{c}^{0} \mid \hat{H}_{W} \mid M^{j_{0}}(8) \rangle \mid [q_{1}q_{2}q_{3}] \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ \sum q_{j} \beta \langle B_{c}^{0} \mid \hat{H}_{W} \mid M^{j_{0}}(8) \rangle \mid q_{3}[q_{1}q_{2}] \langle q_{3}[q_{1}q_{2}] \mid \psi^{k_{0}}(8)_{A23} \rangle$$

$$= \sum _{q,q',q''} \alpha \langle B_{c}^{0} \mid \hat{H}_{W} \mid \bar{q}q' \rangle \mid [q_{1}q_{2}q_{3}] \langle \bar{q}q' \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ \sum _{q,q',q''} \beta \langle B_{c}^{0} \mid \hat{H}_{W} \mid \bar{q}q' \rangle \mid q_{3}[q_{1}q_{2}] \langle \bar{q}q' \mid \phi^{j_{0}}(8) \rangle \langle q_{3}[q_{1}q_{2}] \mid \psi^{k_{0}}(8)_{A23} \rangle.$$  \hspace{1cm} (17)

In this case there are nine kinds of the quark diagrams as depicted in Fig. 1. Type $D_{1}, D'_{1}$ and $G$ consist of two diagrams, one diagram in which the first and the second quarks are antisymmetrized and one diagram in which the second and the third quarks are antisymmetrized. On the other hand type $A, B, C, E, F$ and $H$ consist of only one diagram, because the spectator quarks stay antisymmetric in the final baryons or the quarks produced in the weak interaction are antisymmetric due to the Pati-Woo theorem. Then we reach the following expression of the decay amplitudes:

$$A(i_{0} \to j_{0} k_{0}) = \sum _{q,q',q''} \{ A \langle \bar{q}q'_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ B \langle \bar{q}q_{0}q_{3} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ C \langle \bar{q}q_{3}q_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ D_{1} \langle \bar{q}q_{3}q_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ D_{2} \langle \bar{q}q_{3}q_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A23} \rangle$$

$$+ D'_{1} \langle \bar{q}q_{3}q_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ D'_{2} \langle \bar{q}q_{3}q_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A23} \rangle$$

$$+ E \langle \bar{q}q_{3}q_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle$$

$$+ F \langle \bar{q}q_{3}q_{0} \mid \phi^{j_{0}}(8) \rangle \langle [q_{1}q_{2}]q_{3} \mid \psi^{k_{0}}(8)_{A12} \rangle.$$
\[ G_1 \langle \bar{q}_0 q_2 | \phi^j \rangle \langle [q_3 q_1] q_0 | \psi^{k_0} \rangle_A \]
\[ G_2 \langle \bar{q}_0 q_2 | \phi^j \rangle \langle [q_3 q_1] q_0 | \psi^{k_0} \rangle_A \]
\[ H \langle \bar{q}_0 q_0 | \phi^j \rangle \langle [q_3' q_1] q_0 | \psi^{k_0} \rangle_A \].

Each term corresponds to each diagram of Fig. 1. From the above equation the decay amplitudes are represented in terms of twelve parameters \( A \) etc. These parameters are essentially the same with the parameters \( a \) etc. in Ref. [1], but they differ by only numerical factors. The relations between two sets of parameters are as follows:

\[
A = \frac{8}{\sqrt{6}} a, \quad B = \frac{8}{\sqrt{6}} b, \quad C = \frac{4}{\sqrt{6}} c, \quad D_1 = \frac{4}{\sqrt{6}} d_1, \quad D_2 = -\frac{4}{\sqrt{6}} d_2, \quad D'_1 = \frac{4}{\sqrt{6}} d_3, \quad D'_2 = -\frac{4}{\sqrt{6}} d_4, \quad E = \frac{4}{\sqrt{6}} e, \quad H = -\frac{4}{\sqrt{6}} h. \tag{19}
\]

With these new parameters we can more easily compare with the amplitudes in Ref. [2].

The relations between \( |\psi^k(8)_{A12}\rangle, |\psi^k(8)_{A23}\rangle \) in this paper and \( |\psi^k(8)_A\rangle, |\psi^k(8)_S\rangle \) in Ref. [2] are as follows:

\[
|\psi^k(8)_A\rangle = |\psi^k(8)_{A12}\rangle, \tag{20}
\]
\[
|\psi^k(8)_S\rangle = -\frac{1}{\sqrt{3}} |\psi^k(8)_{A12}\rangle - \frac{2}{\sqrt{3}} |\psi^k(8)_{A23}\rangle, \tag{21}
\]

for all \( k \). From Eqs. (20) and (21) octet baryon states are expressed as

\[
|B^k(8)\rangle = a \ |\psi^k(8)_A\rangle + b \ |\psi^k(8)_S\rangle
= (a - \frac{1}{\sqrt{3}} b) |\psi^k(8)_{A12}\rangle - \frac{2}{\sqrt{3}} b \ |\psi^k(8)_{A23}\rangle. \tag{22}
\]

Comparing with Eq. (15), we obtain

\[
\alpha = a - \frac{1}{\sqrt{3}} b, \quad \beta = -\frac{2}{\sqrt{3}} b. \tag{23}
\]

Therefore the relations between the above parameters \( A \) etc. and the parameters \( A_A \) etc. in Ref. [2] are written as follows:

\[
A = A_A, \quad B = B'_A, \quad C = B_A, \tag{24}
\]
\begin{align*}
D_1 &= C_A' - \frac{1}{\sqrt{3}} C_S', \quad D_2 = -\frac{2}{\sqrt{3}} C_S', \quad D_1' = C_{2A} - \frac{1}{\sqrt{3}} C_{2S}, \\
D_2' &= -\frac{2}{\sqrt{3}} C_{2S}, \quad E = C_{1A}, \quad F = E'_A, \\
G_1 &= E_A - \frac{1}{\sqrt{3}} E_S, \quad G_2 = -\frac{2}{\sqrt{3}} E_S.
\end{align*}

These relations are the same with Eq. (63) in Ref. [2], but they were pointed out first in Ref. [4]. The quark diagram schemes in Ref. [1] and in Ref. [2] are equivalent under these relations. There are many errors in the decay amplitudes of Ref. [2]. The correct decay amplitudes without final state interactions are given in terms of the parameters of this paper in Tables I, II and III. They can be translated into Chau’s amplitudes using Eqs. (24).

We can also use symmetric bases. We define

\begin{align*}
|\{q_a q_b q_c\rangle &= \frac{1}{\sqrt{2}(1 - \delta_{ab}) + 2\delta_{ab}} (|q_a q_b q_c\rangle + |q_b q_a q_c\rangle), \\
|q_c\{q_a q_b\rangle &= \frac{1}{\sqrt{2}(1 - \delta_{ab}) + 2\delta_{ab}} (|q_a q_c q_b\rangle + |q_b q_c q_a\rangle), \\
|\{q_a q_c q_b\rangle &= \frac{1}{\sqrt{2}(1 - \delta_{ab}) + 2\delta_{ab}} (|q_a q_c q_b\rangle + |q_b q_c q_a\rangle).
\end{align*}

The octet baryon states in which the first and the second quarks are symmetric are written as

\begin{align*}
|\psi^{k}(8)_{S12}\rangle &= \frac{1}{\sqrt{3}} \eta_k |\{q_a q_b\} q_c\rangle - \frac{2}{\sqrt{6}} \eta_k |q_a q_c q_b\rangle \quad \text{for } k = p, n, \Sigma^+, \Sigma^-, \Xi^0, \Xi^- , (28) \\
|\psi^{\Xi^0}(8)_{S12}\rangle &= -\frac{1}{\sqrt{6}} |\{sd\} u\rangle - \frac{1}{\sqrt{6}} |\{su\} d\rangle + \frac{2}{\sqrt{6}} |\{du\} s\rangle, (29) \\
|\psi^{\Lambda}(8)_{S12}\rangle &= -\frac{1}{\sqrt{2}} |\{sd\} u\rangle + \frac{1}{\sqrt{2}} |\{su\} d\rangle . (30)
\end{align*}

The symmetric octet states \(|\psi^{k}(8)_{S23}\rangle\) and \(|\psi^{k}(8)_{S31}\rangle\) are defined in the same way. As we are treating only SU(3) octet states, the following equation holds.

\begin{align*}
|\{q_a q_b\} q_c\rangle + |q_c\{q_a q_b\rangle + |\{q_a q_c q_b\} = 0. (31)
\end{align*}
So two of three terms are independent. We adopt $|\{q_a q_b\} q_c\rangle$ and $|q_c\{q_a q_b\}\rangle$ as independent bases. Under the octet conditions

$$ |\{q_a q_b\} q_c\rangle + |\{q_b q_c\} q_a\rangle + |\{q_c q_a\} q_b\rangle = 0 $$ (32)

and

$$ |q_a\{q_b q_c\}\rangle + |q_b\{q_c q_a\}\rangle + |q_c\{q_a q_b\}\rangle = 0, $$ (33)

$|\{q_a q_b\} q_c\rangle$ and $|q_a\{q_b q_c\}\rangle$ constitute a complete set. Though these are not orthogonal, symmetric octet baryon states $|\psi^k(8)_{S12}\rangle$ and $|\psi^k(8)_{S23}\rangle$ can be written using quark symmetric bases $|\{q_a q_b\} q_c\rangle$ and $|q_c\{q_a q_b\}\rangle$ respectively.

$$ |\psi^k(8)_{S12}\rangle = \sum_{q_a, q_b, q_c} |\{q_a q_b\} q_c\rangle \langle\{q_a q_b\} q_c|\psi^k(8)_{S12}\rangle, $$ (34)

$$ |\psi^k(8)_{S23}\rangle = \sum_{q_a, q_b, q_c} |q_c\{q_a q_b\}\rangle \langle q_c\{q_a q_b\}|\psi^k(8)_{S23}\rangle. $$ (35)

Most general form of octet baryon states $|B^k(8)\rangle$ is a combination of the two parts.

$$ |B^k(8)\rangle = \alpha' |\psi^k(8)_{S12}\rangle + \beta' |\psi^k(8)_{S23}\rangle. $$ (36)

The decay amplitudes of antitriplet charmed baryon $B^{i_0}_c$ to an octet baryon $B^{k_0}(8)$ and an octet pseudoscalar meson $M^{j_0}(8)$ are written as follows:

$$ A(i_0 \to j_0 k_0) = \sum_{\bar{q}_i, q_i, q_i'} \alpha' \langle B^{i_0}_c|\hat{H}_W|\bar{q} q'\rangle \langle q_1 q_2 q_3\rangle \langle q_1 q_2|\phi^{j_0}(8)\rangle \langle q_3|\psi^{k_0}(8)_{S12}\rangle + \sum_{\bar{q}_i, q_i, q_i'} \beta' \langle B^{i_0}_c|\hat{H}_W|\bar{q} q'\rangle \langle q_1\{q_2 q_3\}\rangle \langle \bar{q} q'|\phi^{j_0}(8)\rangle \langle q_3\{q_1 q_2\}|\psi^{k_0}(8)_{S23}\rangle. $$ (37)

In this case there are nine kinds of quark diagrams as depicted in Fig. 2. Each type consists of two diagrams, one diagram in which the first and the second quarks are symmetrized and one diagram in which the second and the third quarks are symmetrized. In type $A_S, B_S$ and $F_S$ diagrams the spectator quarks $q_1$ and $q_2$ are antisymmetric and in type $C_S, E_S$ and $H_S$ diagrams the quarks produced in the weak interaction are antisymmetric, so we must take the difference of two diagram contributions. Then the expression of the
The relations decay amplitudes is

\[
A(i_0 \to j_0 k_0) = \sum_{q,q',q_i} \left\{ A_S \langle \bar{q}_0 q_0 | \phi^{j_0}(8) \rangle \left( \langle q_2 q_3 | \psi^{k_0}(8)_{S12} \rangle - \langle q_2 q_3 | \psi^{k_0}(8)_{S23} \rangle \right) + B_S \langle \bar{q}_0 q_3 | \phi^{j_0}(8) \rangle \left( \langle q_2 q_3 | \psi^{k_0}(8)_{S12} \rangle - \langle q_2 q_3 | \psi^{k_0}(8)_{S23} \rangle \right) + C_S \langle \bar{q}_0 q_2 | \phi^{j_0}(8) \rangle \left( \langle q_3 q_1 | \psi^{k_0}(8)_{S12} \rangle - \langle q_3 q_1 | \psi^{k_0}(8)_{S23} \rangle \right) + D_{S1} \langle \bar{q}_0 q_3 | \phi^{j_0}(8) \rangle \langle q_2 q_0 | \psi^{k_0}(8)_{S12} \rangle + D_{S2} \langle \bar{q}_0 q_3 | \phi^{j_0}(8) \rangle \langle q_2 q_1 | \psi^{k_0}(8)_{S23} \rangle + D'_{S1} \langle \bar{q}_0 q_2 | \phi^{j_0}(8) \rangle \langle q_3 q_0 | \psi^{k_0}(8)_{S12} \rangle + D'_{S2} \langle \bar{q}_0 q_2 | \phi^{j_0}(8) \rangle \langle q_3 q_1 | \psi^{k_0}(8)_{S23} \rangle + E_S \langle \bar{q}_0 q_2 | \phi^{j_0}(8) \rangle \left( \langle q_3 q_0 | q_1' | \psi^{k_0}(8)_{S12} \rangle - \langle q_3 q_0 | q_1' | \psi^{k_0}(8)_{S23} \rangle \right) + F_S \langle \bar{q}_0 q_3 | \phi^{j_0}(8) \rangle \left( \langle q_2 q_0 | q_1 | \psi^{k_0}(8)_{S12} \rangle - \langle q_2 q_0 | q_1 | \psi^{k_0}(8)_{S23} \rangle \right) + G_{S1} \langle \bar{q}_0 q_2 | \phi^{j_0}(8) \rangle \langle q_1 q_0 | q_3 | \psi^{k_0}(8)_{S12} \rangle + G_{S2} \langle \bar{q}_0 q_2 | \phi^{j_0}(8) \rangle \langle q_1 q_0 | q_3 | \psi^{k_0}(8)_{S23} \rangle + H_S \langle \bar{q}_0 q_0 | \phi^{j_0}(8) \rangle \left( \langle q_3 q_1 | q_2' | \psi^{k_0}(8)_{S12} \rangle - \langle q_3 q_1 | q_2' | \psi^{k_0}(8)_{S23} \rangle \right) \right\}. \tag{38}
\]

The factor \( \sqrt{2}(1 - \delta_{q,q_i}) + 2 \delta_{q,q_i} \) was dropped in each term for simplicity.

The decay amplitudes were represented in terms of the above twelve parameters. From the relations

\[
|\psi^k(8)_S\rangle = |\psi^k(8)_{S12}\rangle \tag{39}
\]

and

\[
|\psi^k(8)_A\rangle = \frac{1}{\sqrt{3}} |\psi^k(8)_{S12}\rangle + \frac{2}{\sqrt{3}} |\psi^k(8)_{S23}\rangle, \tag{40}
\]

octet baryon states \( |B^k(8)\rangle \) are written as

\[
|B^k(8)\rangle = a \, |\psi^k(8)_A\rangle + b \, |\psi^k(8)_S\rangle = \left( \frac{1}{\sqrt{3}} \, a + b \right) |\psi^k(8)_{S12}\rangle + \frac{2}{\sqrt{3}} a \, |\psi^k(8)_{S23}\rangle. \tag{41}
\]
Relations between the above parameters \( (A_S \text{ etc.}) \) and the parameters \( (A_A \text{ etc.}) \) in Ref. [2] are derived from this equation.

\[
A_S = \frac{1}{\sqrt{3}} A_A, \quad B_S = \frac{1}{\sqrt{3}} B'_A, \quad C_S = \frac{1}{\sqrt{3}} B_A, \\
D_{S1} = C'_S + \frac{1}{\sqrt{3}} C'_A, \quad D_{S2} = \frac{2}{\sqrt{3}} C'_S, \quad D'_{S1} = C_{2A} + \frac{1}{\sqrt{3}} C_{2S}, \\
D'_{S2} = \frac{2}{\sqrt{3}} C_{2S}, \quad E_S = \frac{1}{\sqrt{3}} C_{1A}, \quad G_{S1} = E_A + \frac{1}{\sqrt{3}} E_S, \\
G_{S2} = \frac{2}{\sqrt{3}} E_S, \quad F_S = \frac{1}{\sqrt{3}} E'_A. \tag{42}
\]

Thus this symmetric scheme is also equivalent to Chau’s scheme under these relations.

In conclusion, though octet baryon states can be represented in some different forms, they lead to equivalent decay amplitudes in the quark diagram scheme. The relations among the different representations were obtained like Eqs. (24) and (42).
References

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TABLE I. Cabibbo-allowed decay amplitudes

| Decay modes | Amplitudes |
|-------------|------------|
| $\Lambda_c^+ \rightarrow p\bar{K}^0$ | $\frac{1}{2}(B + D_2)$ |
| $\rightarrow \Lambda\pi^+$ | $-\frac{1}{2\sqrt{6}}(2A + C + D'_1 + D'_2 - E)$ |
| $\rightarrow \Sigma^0\pi^+$ | $\frac{1}{2\sqrt{2}}(C + D'_1 - D'_2 - E)$ |
| $\rightarrow \Sigma^+\pi^0$ | $\frac{1}{2\sqrt{2}}(-C - D'_1 + D'_2 + E)$ |
| $\rightarrow \Sigma^+\eta_1$ | $\frac{1}{2\sqrt{3}}(C - D_2 - D'_1 + D'_2 + E - 3H)$ |
| $\rightarrow \Sigma^+\eta_8$ | $\frac{1}{2\sqrt{6}}(C + 2D_2 - D'_1 + D'_2 + E)$ |
| $\rightarrow \Xi^0K^+$ | $\frac{1}{2}(-D'_1 + E)$ |
| $\Xi^+_c \rightarrow \Sigma^+\bar{K}^0$ | $\frac{1}{2}(B - C)$ |
| $\rightarrow \Xi^0\pi^+$ | $\frac{1}{2}(A + C)$ |
| $\Xi^0_c \rightarrow \Lambda\bar{K}^0$ | $\frac{1}{2\sqrt{6}}(-B - C + D_1 - 2D_2 + E)$ |
| $\rightarrow \Sigma^0\bar{K}^0$ | $\frac{1}{2\sqrt{2}}(-B + C - D_1 - E)$ |
| $\rightarrow \Sigma^+K^-$ | $\frac{1}{2}(D_1 + E)$ |
| $\rightarrow \Xi^-\pi^+$ | $-\frac{1}{2}(A + D'_2)$ |
| $\rightarrow \Xi^0\pi^0$ | $\frac{1}{2\sqrt{2}}(-C + D'_2)$ |
| $\rightarrow \Xi^0\eta_1$ | $\frac{1}{2\sqrt{3}}(C + D_1 - D_2 + D'_2 + E - 3H)$ |
| $\rightarrow \Xi^0\eta_8$ | $\frac{1}{2\sqrt{6}}(C - 2D_1 + 2D_2 + D'_2 - 2E)$ |
TABLE II. Cabibbo-suppressed decay amplitudes

| Decay modes | Amplitudes |
|-------------|------------|
| $\Lambda_c^+ \rightarrow \Sigma^0 K^+$ | $\frac{1}{2\sqrt{2}}(C - D'_2 - G_2)$ |
| $\rightarrow \Sigma^+ K^0$ | $\frac{1}{2}(C + D_2 - G_2)$ |
| $\rightarrow \Lambda K^+$ | $-\frac{1}{2\sqrt{6}}(2A + C - 2D'_1 + D'_2 + 2E + 2F - 2G_1 + G_2)$ |
| $\rightarrow n\pi^+$ | $\frac{1}{2}(-A - C - D'_1 + E + F - G_1)$ |
| $\rightarrow p\pi^0$ | $\frac{1}{2\sqrt{2}}(B - C + D_2 - D'_1 + D'_2 + E + F - G_1)$ |
| $\rightarrow p\eta_1$ | $\frac{1}{2\sqrt{6}}(C - D_2 - D'_1 + D'_2 + E + F - G_1 + 2G_2 - 3H)$ |
| $\rightarrow p\eta_8$ | $\frac{1}{2\sqrt{6}}(-3B + C - D_2 - D'_1 + D'_2 + E + F - G_1 + 2G_2)$ |
| $\Xi_c^+ \rightarrow \Sigma^0\pi^+$ | $\frac{1}{2\sqrt{2}}(A - D'_1 + D'_2 + E - F + G_1 - G_2)$ |
| $\rightarrow \Sigma^+\pi^0$ | $\frac{1}{2\sqrt{2}}(B + D'_1 - D'_2 - E + F - G_1 + G_2)$ |
| $\rightarrow \Sigma^+\eta_1$ | $\frac{1}{2\sqrt{6}}(-C + D_2 + D'_1 - D'_2 - E + F - G_1 + 2G_2 + 3H)$ |
| $\rightarrow \Sigma^+\eta_8$ | $\frac{1}{2\sqrt{6}}(-3B + 2C - 2D_2 + D'_1 - D'_2 - E + F - G_1 - G_2)$ |
| $\rightarrow \Lambda\pi^+$ | $\frac{1}{2\sqrt{6}}(-A - 2C + D'_1 + D'_2 - E + F - G_1 - G_2)$ |
| $\rightarrow \Xi^0 K^+$ | $\frac{1}{2}(A + C + D'_1 - E + F - G_1)$ |
| $\rightarrow p\bar{K}^0$ | $\frac{1}{2}(C + D_2 + G_2)$ |

(continued)
| Decay modes | Amplitudes |
|-------------|------------|
| $\Xi^0_c \to \Sigma^+\pi^-$ | $-\frac{1}{2}(D_1 + E + G_1 - G_2)$ |
| $\to \Sigma^-\pi^+$ | $-\frac{1}{2}(-A - D_2' + F)$ |
| $\to \Sigma^0\pi^0$ | $-\frac{1}{4}(B + D_1 - D_2' + E + G_1 - G_2)$ |
| $\to \Sigma^0\eta_1$ | $\frac{1}{2\sqrt{6}}(-B + C + D_1 - D_2 + D_2' + E - F + G_1 - 2G_2 - 3H)$ |
| $\to \Sigma^0\eta_8$ | $\frac{1}{4\sqrt{3}}(3B - 2C + D_1 + 2D_2 + D_2' + E - F + G_1 + G_2)$ |
| $\to \Lambda\pi^0$ | $\frac{1}{2\sqrt{3}}(-B + 2C + D_1 - 2D_2 - 3D_2' + E - F + G_1 + G_2)$ |
| $\to \Lambda\eta_1$ | $\frac{1}{6\sqrt{2}}(-3C - 3D_1 + 3D_2 - 3D_2' - 3E - F + G_1 - 2G_2 + 9H)$ |
| $\to \Lambda\eta_8$ | $\frac{1}{12}(3B + 3D_1 - 3D_2' + 3E - F - 5G_1 + G_2)$ |
| $\to \Xi^0K^0$ | $\frac{1}{2}(C - D_1 + D_2 - E - G_1)$ |
| $\to \Xi^-K^+$ | $-\frac{1}{2}(A + D_2' + F)$ |
| $\to pK^-$ | $\frac{1}{2}(D_1 + E - G_1 + G_2)$ |
| $\to n\bar{K}^0$ | $\frac{1}{2}(-C + D_1 - D_2 + E - G_1)$ |
| Decay modes | Amplitudes |
|-------------|------------|
| $\Lambda_c^+ \to pK^0$ | $\frac{1}{2}(B - C)$ |
| $\to nK^+$ | $\frac{1}{2}(A + C)$ |
| $\Xi_c^+ \to \Sigma^0 K^+$ | $-\frac{1}{2\sqrt{2}}(A + D'_2)$ |
| $\to \Sigma^+ K^0$ | $\frac{1}{2}(B + D_2)$ |
| $\to \Lambda K^+$ | $\frac{1}{2\sqrt{6}}(A + 2C + 2D'_1 - D'_2 - 2E)$ |
| $\to n\pi^+$ | $\frac{1}{2}(-D'_1 + E)$ |
| $\to p\pi^0$ | $\frac{1}{2\sqrt{2}}(D_2 - D'_1 + D'_2 + E)$ |
| $\to p\eta_1$ | $\frac{1}{2\sqrt{3}}(C - D_2 - D'_1 + D'_2 + E - 3H)$ |
| $\to p\eta_8$ | $-\frac{1}{2\sqrt{6}}(2C + D_2 + D'_1 - D'_2 - E)$ |
| $\Xi_c^0 \to \Lambda K^0$ | $-\frac{1}{2\sqrt{6}}(B - 2C + 2D_1 - D_2 + 2E)$ |
| $\to \Sigma^0 K^0$ | $-\frac{1}{2\sqrt{2}}(B + D_2)$ |
| $\to \Sigma^- K^+$ | $-\frac{1}{2}(A + D'_2)$ |
| $\to p\pi^-$ | $\frac{1}{2}(D_1 + E)$ |
| $\to n\pi^0$ | $-\frac{1}{2\sqrt{2}}(D_1 - D_2 - D'_2 + E)$ |
| $\to n\eta_1$ | $\frac{1}{2\sqrt{3}}(C + D_1 - D_2 + D'_2 + E - 3H)$ |
| $\to n\eta_8$ | $-\frac{1}{2\sqrt{6}}(2C - D_1 + D_2 - D'_2 - E)$ |
Fig. 1. Quark diagrams in antisymmetric bases
Fig. 2. Quark diagrams in symmetric bases