Decay coupling constants sum for dibaryon octet into two baryon octets with λ8 first order SU(3) symmetry breaking

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1. Introduction

- Quarks (confined by color force): q and $\bar{q}$
- Nature (color singlets):
  - Baryons $(q_1 q_2 q_3) \equiv B$
  - Mesons $(q_1 \overline{q_2}) \equiv M$
  - Multiquark states
- Multiquark states:
  - Tetraquarks $(\underbrace{q_1 \overline{q_2}}_{M}\ \underbrace{q_3 \overline{q_4}}_{M'})$
  - Pentaquarks $(\underbrace{q_1 q_2 q_3}_{B}\ \underbrace{q_4 \overline{q_5}}_{M})$
  - Hexaquarks
  - Etc.

- Hexaquarks:
  - Baryon number = 0
    - $(\overbrace{q_1 q_2 q_3}^{B} \overbrace{\bar{q}_4 \bar{q}_5 \bar{q}_6}^{B'}) \equiv B_6$
    - $(\overbrace{q_1 \bar{q}_2}^{M} \overbrace{q_3 \bar{q}_4}^{M'} \overbrace{q_5 \bar{q}_6}^{M''}) \equiv M_6$
  - Baryon number = 2
    - $(\overbrace{q_1 q_2 q_3}^{B} \overbrace{q_4 q_5 q_6}^{B}) \equiv B_6$

(a stable dibaryon already exists in nature: deuteron (pn)).

- Dibaryons $SU(3)$ [1-5]

$$\underbrace{1 \oplus 8_S \oplus 8_A \oplus 10 \oplus \overline{10} \oplus 27}_{\text{dibaryon multiplets}} \quad = \quad \underbrace{8 \otimes 8}_{\text{baryon octet + baryon octec}}$$

- (deuteron belongs to the dibaryon $\overline{10}$ multiplet $D\overline{10}$ [1]).

[1] R. J. Oakes, *Phys. Rev.* **131**, 2239 (1963).

[2] R. L. Jaffe, *Phys. Rev. Lett.* **38**, 195 (1977).

[3] S-Q Xie and Q-R. Zhang, *Phys. Lett.* **143B**, 441 (1984).

[4] M. Oka, *Phys. Rev. D* **38**, 298 (1988).

[5] S. D. Paganis, *et al., Phys. Rev. C* **62,** 024906 (2000).

2. Notation

Sum rules for strong decay coupling constants of dibaryon octets into two ordinary baryon octets $\left(8_{S,\mathrm{A}} \to 8 \oplus 8\right)$ with first order SU(3) symmetry breaking are determined (recently, sum rules for strong decays of dibaryon decuplets into two baryon octets $(10, \overline{10} \to 8 \oplus 8)$were determined in Ref. [6])

[6] V. Gupta and G. Sánchez-Colón, *Mod. Phys. Lett. A* **30**, 1550010 (2015).

Notation [7]

Ordinary octet baryon:

$$B_8 = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ -\Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}$$

Dibaryon octet:

$$D_8 = \begin{pmatrix} \frac{1}{\sqrt{6}}D_8(0,0,0) + \frac{1}{\sqrt{2}}D_8(0,1,0) & D_8(0,1,+1) & D_8(1,1/2,+1/2) \\ D_8(0,1,-1) & \frac{1}{\sqrt{6}}D_8(0,0,0) - \frac{1}{\sqrt{2}}D_8(0,1,0) & D_8(1,1/2,-1/2) \\ -D_8(-1,1/2,-1/2) & D_8(-1,1/2,+1/2) & -\sqrt{\frac{2}{3}}D_8(0,0,0) \end{pmatrix}$$

the (Y, I, I_3) states of D_8 are denoted by $D_8(Y,I,I_3)$ with Y hypercharge, I Isospin, and I_3 isospin third component.

[7] P. A. Carruthers, *Introduction to Unitary Symmetry* (Interscience, USA 1966).

3. Strong decay coupling constants

3.1. SU(3) SYMMETRY LIMIT

Interaction Hamiltonian for Yukawa couplings [8]:

$$H_0^{int} \equiv g_8^0 \mathrm{Tr}[\overline{D}_8(B_8B_8' + B_8'B_8)] + g_{8'}^0 \mathrm{Tr}[\overline{D}_8(B_8B_8' - B_8'B_8)]$$

⇒ 2 parameters: g_8^0 and $g_{8'}^0$ for symmetric and antisymmetric final state, respectively.

[8] M. Muraskin and S. L. Glashow, *Phys. Rev.* **132**, 482 (1963).

3.2. FIRST ORDER SU(3) SYMMETRY BREAKING

SU(3) symmetry breaking interaction transforms like the hypercharge Y [7]:

$$\lambda_8 = \frac{1}{\sqrt{3}}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

- **Symmetric final state [8]:**

$$H_S^{int} \equiv g_1' \mathrm{Tr}[\overline{D}_8 \lambda_8 (B_8 B_8' + B_8' B_8)] + g_2' \mathrm{Tr}[\overline{D}_8 \lambda_8 (B_8 B_8' + B_8' B_8)\lambda_8] + g_3' (\mathrm{Tr}[\overline{D}_8 B_8] \mathrm{Tr}[B_8' \lambda_8] + \mathrm{Tr}[\overline{D}_8 B_8'] \mathrm{Tr}[B_8 \lambda_8]) + g_4' \mathrm{Tr}[\overline{D}_8 \lambda_8] \mathrm{Tr}[B_8 B_8']$$

$\Longrightarrow$ 5 parameters in total: g_8^0 and g_k', k=1,2,3,4.

- **Antisymmetric final state [8]:**

$$H_S^{int} \equiv g_1 \mathrm{Tr}[\overline{D}_8 \lambda_8 (B_8 B_8' - B_8' B_8)] + g_2 \mathrm{Tr}[\overline{D}_8 \lambda_8 (B_8 B_8' - B_8' B_8)\lambda_8] + g_3 \mathrm{Tr}[\overline{D}_8 (B_8 B_8' - B_8' B_8)\lambda_8] + g_4 (\mathrm{Tr}[\overline{D}_8 B_8] \mathrm{Tr}[B_8' \lambda_8] - \mathrm{Tr}[\overline{D}_8 B_8] \mathrm{Tr}[B_8' \lambda_8])$$

$\Longrightarrow$ 5 parameters in total: g_8^0 and g_k, k=1,2,3,4.

[8] M. Muraskin and S. L. Glashow, *Phys. Rev.* **132**, 482 (1963).

4. Sum rules

4.1. SYMMETRIC FINAL STATE

9 independent strong decay coupling constants described in terms of 5 parameters (g_8^0, and $g_{k'}$) $\Longrightarrow$ 4 sum rules:

$$\sqrt{6}\,G[D_8(1,1/2,+1/2)\to p\,\Lambda'] = -\sqrt{2}\,G[D_8(1,1/2,+1/2)\to p\,\Sigma^{0\prime}] \\ -\sqrt{6}\,G[D_8(-1,1/2,+1/2)\to \Lambda\,\Xi^{0\prime}] + G[D_8(-1,1/2,+1/2)\to \Sigma^+\,\Xi^{-\prime}],$$

$$\sqrt{6}\,G[D_8(0,1,+1)\to \Sigma^+\,\Lambda'] = -2\,G[D_8(0,1,+1)\to p\,\Xi^{0\prime}] \\ -\sqrt{6}\,G[D_8(-1,1/2,+1/2)\to \Lambda\,\Xi^{0\prime}] + G[D_8(-1,1/2,+1/2)\to \Sigma^+\,\Xi^{-\prime}],$$

$$\sqrt{6}\, G[D_8(0,0,0) \to p\, \Xi^{-\prime}] = 2\sqrt{2}\, G[D_8(1,1/2,+1/2) \to p\, \Sigma^{0\prime}]$$
$$+\, G[D_8(0,1,+1) \to p\, \Xi^{0\prime}] + \sqrt{6}\, G[D_8(0,0,0) \to \Sigma^+\, \Sigma^{-\prime}]$$
$$+\, 2\, G[D_8(-1,1/2,+1/2) \to \Sigma^+\, \Xi^{-\prime}],$$

$$3\sqrt{3}\, G\, [D_8(0,0,0) \to \Lambda\, \Lambda'] = -8\, G[D_8(1,1/2,+1/2) \to p\, \Sigma^{0\prime}]$$
$$-\, 2\sqrt{2}\, G[D_8(0,1,+1) \to p\, \Xi^{0\prime}] - 3\sqrt{3}\, G[D_8(0,0,0) \to \Sigma^+\, \Sigma^{-\prime}]$$
$$-\, 6\sqrt{3}\, G[D_8(-1,1/2,+1/2) \to \Lambda\, \Xi^{0\prime}] - \sqrt{2}\, G[D_8(-1,1/2,+1/2) \to \Sigma^+\, \Xi^{-\prime}].$$

With identical relationships for $G[D_8(Y,I,I3 \longrightarrow B'B)]$=+ $G[D_8(Y,I,I3 \longrightarrow B'B)]$.

4.2. ANTISYMMETRIC FINAL STATE

8 independent strong decay coupling constants described in terms of 5 parameters (g_8^0 and g_k) $\Longrightarrow$ 3 sum rules:

$$
\begin{aligned}
4\,G[D_8(1,1/2,+1/2) \to p\,\Sigma^{0\prime}] &= 2\sqrt{3}\,G[D_8(0,0,0) \to p\,\Xi^{-\prime}] \\
&- \sqrt{2}\,G[D_8(0,1,+1) \to p\,\Xi^{0\prime}] + 2\,G[D_8(0,1,+1) \to \Sigma^+\,\Sigma^{0\prime}] \\
&- 2\sqrt{2}\,G[D_8(-1,1/2,+1/2) \to \Sigma^+\,\Xi^{-\prime}],
\end{aligned}
$$

$$
\begin{aligned}
2\sqrt{6}\,G[D_8(1,1/2,+1/2) \to p\,\Lambda'] &= 3\sqrt{6}\,G[D_8(0,0,0) \to p\,\Xi^{-\prime}] \\
&+ 5\,G[D_8(0,1,+1) \to p\,\Xi^{0\prime}] - \sqrt{2}\,G[D_8(0,1,+1) \to \Sigma^+\,\Sigma^{0\prime}] \\
&+ 2\sqrt{6}\,G[D_8(-1,1/2,+1/2) \to \Xi^0\,\Lambda'],
\end{aligned}
$$

$$
\begin{aligned}
&\sqrt{6}\,G[\,D_8(0,1,+1) \to \Sigma^+\,\Lambda'\,] = \\
&\quad = 2\,G[D_8(0,1,+1) \to p\,\Xi^{0\prime}] - \sqrt{2}\,G[D_8(0,1,+1) \to \Sigma^+\,\Sigma^{0\prime}] \\
&\quad + 3\,G[D_8(-1,1/2,+1/2) \to \Sigma^+\,\Xi^{-\prime}] + \sqrt{6}\,G[D_8(-1,1/2,+1/2) \to \Xi^0\,\Lambda'],
\end{aligned}
$$

With identical relationships for $G[D_8(Y,I,I3 \longrightarrow B'B)] = -\,G[D_8(Y,I,I3 \longrightarrow B'B)]$.

5. Concluding remarks

- Hexaquarks states with baryon number 2, dibaryons, were considered.
- Earlier, sum rules for strong decays of dibaryon decuplets into two ordinary baryon octets have been calculated [6].
- In this work sum rules for strong decay coupling constants of dibaryon octet into two ordinary baryon octets with first order SU(3) symmetry breaking were determined.
- Next steps: experimental data input, sum rules for strong decays of the dibaryon 27-plet into two baryons, extension to SU(4) symmetry, … .