Decay coupling constants sum rules for dibaryon octet into two baryon octets with 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 $(q_1 \bar{q}_2) \equiv M$

  Multiquark states

- Multiquark states: Tetraquarks $(\overbrace{q_1 \bar{q}_2}^{M}\, \overbrace{q_3 \bar{q}_4}^{M'})$

  Pentaquarks $(\overbrace{q_1 q_2 q_3}^{B}\, \overbrace{q_4 \bar{q}_5}^{M})$

  Hexaquarks

  Etc.

$$
\bullet\ \text{Hexaquarks:}\quad
\begin{cases}
\text{Baryon number} = 0 & \begin{cases} (\overbrace{q_1 q_2 q_3}^{B}\overbrace{\bar{q}_4 \bar{q}_5 \bar{q}_6}^{\bar{B}'}) \equiv B_6 \\ \left(\overbrace{q_1 \bar{q}_2}^{M}\overbrace{q_3 \bar{q}_4}^{M'}\overbrace{q_5 \bar{q}_6}^{M''}\right) \equiv M_6 \end{cases} \\
\text{Baryon number} = 2 & \left\{ (\overbrace{q_1 q_2 q_3}^{B}\overbrace{q_4 q_5 q_6}^{B'}) \equiv D \quad \textbf{Dibaryon} \right.
\end{cases}
$$

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

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

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

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

2. Abstract and notation

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

● 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.

3. Strong decay coupling constants

3.1. SU(3) SYMMETRY LIMIT

Interaction Hamiltonian for Yukawa couplings [8]:

$$H_0^{\text{int}} \equiv g_8^0 \,\text{Tr}[\overline{D_8}\,(B_8 B_8' + B_8' B_8)] + g_{8'}^0 \,\text{Tr}[\overline{D_8}\,(B_8 B_8' - B_8' B_8)]$$

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

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]:

$$H_{\mathrm{S}}^{\mathrm{int}} \equiv g_1' \mathrm{Tr}[\overline{D_8}\, \lambda_8 (B_8 B_8' + B_8' B_8)] + g_2' \mathrm{Tr}[\overline{D_8} (B_8 B_8' + B_8' B_8) \lambda_8]$$

$$+ g_3' (\mathrm{Tr}[\overline{D_8} B_8] \mathrm{Tr}[B_8' \lambda_8] + \mathrm{Tr}[\overline{D_8} B_8'] \mathrm{Tr}[B_8 \lambda_8]) + g_4' \mathrm{Tr}[\overline{D_8} \lambda_8] \mathrm{Tr}[B_8 B_8']$$

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

• Antisymmetric final state [8]:

$$H_{\mathrm{A}}^{\mathrm{int}} \equiv g_1 \mathrm{Tr}[\overline{D_8}\, \lambda_8 (B_8 B_8' - B_8' B_8)] + g_2 \mathrm{Tr}[\overline{D_8} (B_8 \lambda_8 B_8' - B_8' \lambda_8 B)]$$

$$+ g_3 \mathrm{Tr}[\overline{D_8} (B_8 B_8' - B_8' B_8) \lambda_8] + \ g_4 (\mathrm{Tr}[\overline{D_8} B_8] \mathrm{Tr}[B_8' \lambda_8] - \mathrm{Tr}[\overline{D_8} B_8'] \mathrm{Tr}[B_8 \lambda_8])$$

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

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:

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

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

$$\sqrt{6}\,G[D_{\mathbf{8}}(0,0,0)\to p\,\Xi^{-\prime}] = 2\sqrt{2}\,G[D_{\mathbf{8}}(1,1/2,+1/2)\to p\,\Sigma^{0\prime}]$$
$$+\,G[D_{\mathbf{8}}(0,1,+1)\to p\,\Xi^{0\prime}] + \sqrt{6}\,G[D_{\mathbf{8}}(0,0,0)\to \Sigma^{+}\,\Sigma^{-\prime}]$$
$$+\,2\,G[D_{\mathbf{8}}(-1,1/2,+1/2)\to \Sigma^{+}\,\Xi^{-\prime}],$$

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

With identical relationships for $G[D_8(Y, I, I_3 \longrightarrow B'B)] = +\,G[D_8(Y, I, I_3 \longrightarrow B'B)]$.

4.2. ANTISYMMETRIC FINAL STATE

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

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

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

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

With identical relationships for $G[D_8(Y,I,I_3 \longrightarrow B'B)] = -\,G[D_8(Y,I,I_3 \longrightarrow B'B)]$.

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, … .

6. References

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