Pentaquarks in SU(3) quark model

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hep-ph/0310117 PRD(04) : Oh,Kim,Lee

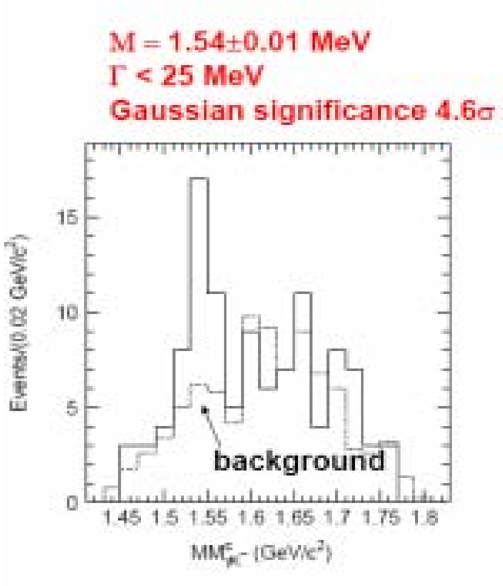
hep-ph/0405010 (to appear in PRD): Oh,Kim

hep-ph/0402135: Lee,Kim,Oh

◆ Exotic Θ^+ observed in KN channel with mass around 1540 MeV and the width less than 20 MeV.

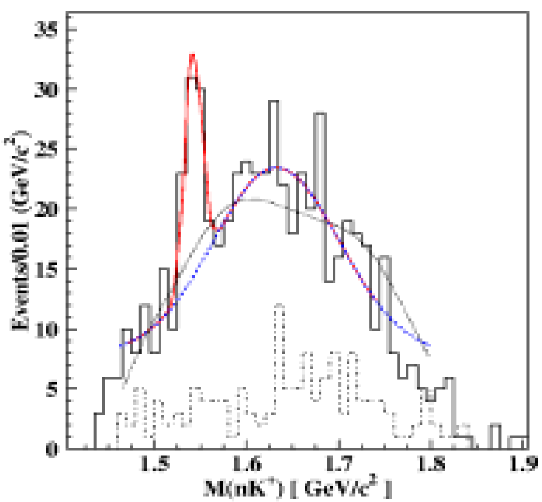
LEPS(Spring-8)

$$\gamma n \to K^+K^-n$$



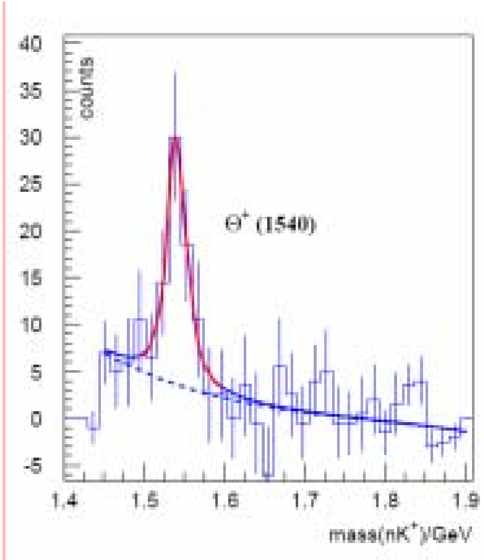
CLAS(Jlab)

$$\gamma d \to K^+K^-pn$$



SAPHIR(Bonn)

$$\gamma p \to K^+K_S^0 n$$



Basic reaction	$M(\Theta^+)$ in MeV	$\Gamma(\Theta^+)$ in MeV	Collaboration/Reference
$\gamma n \to K^+K^-n$	1540 ± 10	≤ 25	LEPS
$K^+\mathrm{Xe} \to K^0p\mathrm{Xe}'$	1539 ± 2	≤ 9	DIANA
$\gamma d \to K^+K^-pn$	1542 ± 5	≤ 21	CLAS
$\gamma p \to K^+K^0_S n$	$1540 \pm 4 \pm 2$	≤ 25	SAPHIR
$\gamma p \to \pi^+K^-K^+n$	1537 ± 10	≤ 31	CLAS
$\nu_\mu(\overline{\nu}_\mu) + A \to \mu^-(\mu^+)pK^0_S X$	1533 ± 5	≤ 20	BBCN
$\gamma p \to \pi^+K^-K^+n$	1555 ± 10	≤ 26	CLAS
$ed \to pK^0_s X$	$1528 \pm 2.6 \pm 2.1$	$13 \pm 9 \pm 3$	HERMES
$pp \to \Sigma^+K^0p$	1530 ± 5	≤ 18	COSY

TABLE I: Summary of the experimental data for the $\Theta^+(1540)$ baryon.

Beware that there are lots of other experiments reporting null results also !

Minimal quark content is $uud d\bar{s}$ (5 quarks !) $S = +1$

$$\Theta^{+} \rightarrow K^{+}(u\bar{s})\; n(udd)$$
$$K^{0}(d\bar{s})\; p(uud)$$

Not a bound state of KN because $m_{\Theta}(1540) > m_{N}(940) + m_{K}(495)$

- Exotic $\Xi^{--}(1862)$ ($dsds\bar{u}$) observed in NA49 (CERN) in pp collisions.

- Anti-charmed analogue, $\Theta_{c}(3099)$ [$udud\bar{c}$] is reported at HERA in the $D^{*}N$ channel.

$\Longrightarrow$ Evidences for the pentaquark are accumulating and we need systematic compilation of pentaquark properties.

SU(3) quark model is expected to be useful in classifying the possible pentaquark states and their properties.
We present all the possible pentaquarks, selection rules for their decays, mass relations.

1. Pentaquark multiplets → classify all the possible pentaquarks
2. Tensor notation and its assignment to the pentaquarks
3. SU(3) lagrangian and mass relations in tensor notation
4. Pentaquarks in J&W model and their decays

Pentaquark multiplets

General classification

$$q^4\bar{q} \quad 3\otimes 3\otimes 3\otimes 3\otimes \bar{3} = 35\oplus 27\oplus \overline{10}\oplus 10\oplus 8\oplus 1$$

Total 91 pentaquarks. The possible multiplets can be reduced under certain model.

Hypercharge Y runs from -3 to 2

Pentaquark nomenclature based on Y and I

Y=2, Θ
Y=1, **N,** Δ
Y=0, Σ, Λ
Y=-1, Ξ
Y=-2, Ω
Y=-3, **X → unique**

Notation for the resonance

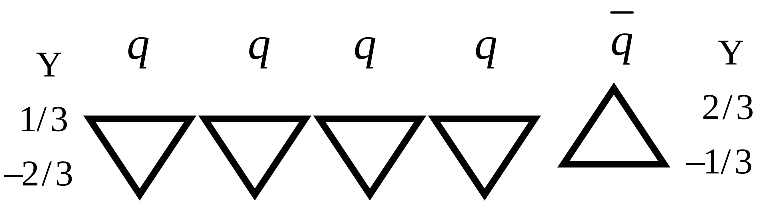
$$\Sigma_{27,2}$$

Obvious subscripts will be omitted

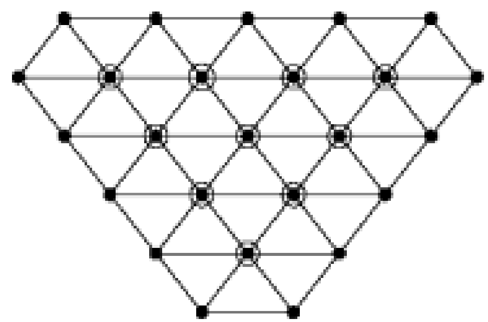
Multiplet that the resonance sits in

Isospin

To classify the states according to Y and I, let us draw the weight diagram

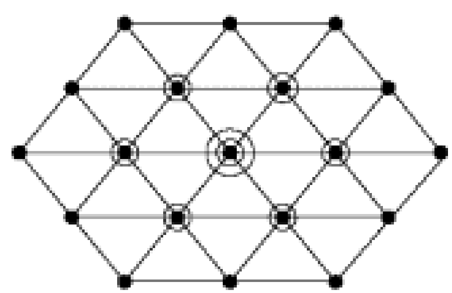


Highest mulitplet 35 →



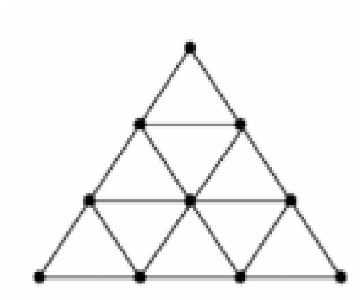
Y	I	
2	2	Θ_2
-1	5/2,3/2	$\Delta_{5/2}, \Delta_{3/2}$
0	2,1	$\Sigma_{35,2}, \Sigma_{35}$
-1	3/2,1/2	$\Xi_{35,3/2}\ \Xi_{35}$
-2	1,0	$\Omega_{35,1}, \Omega_{35}$
-3	1/2	X

27



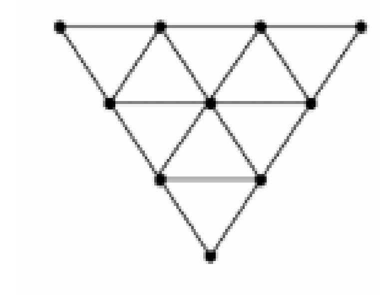
Y	I	
2	1	Θ_1
1	3/2, 1/2	N_{27}, Δ_{27}
0	2, 1, 0	$\Sigma_{27,2}, \Sigma_{27,1}, \Lambda_{27}$
-1	3/2, 1/2	$\Xi_{27,3/2}\ \Xi_{27}$
-2	1	$\Omega_{27,1}$

$\overline{10}$



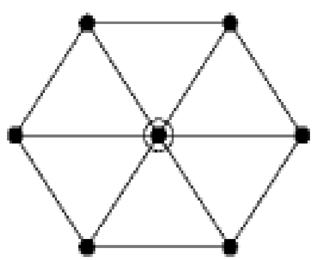
Y	I	
2	0	Θ^{+}
1	1/2	$N_{\overline{10}}$
0	1	$\Sigma_{\overline{10}}$
−1	3/2	$\Xi_{\overline{10},3/2}$

10



Y	I	
1	3/2	Δ_{10}
0	1	Σ_{10}
−1	1/2	Ξ_{10}
−2	0	Ω_{10}

8



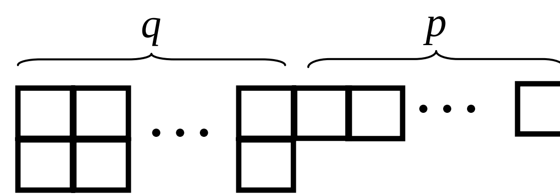
Y	I	
1	1/2	N_8
0	1, 0	Σ_8, Λ_8
−1	1/2	Ξ_8

1 Y=0, I=0 Λ_1

Tensor notation

:useful for constructing mass relations, SU(3) symmetric couplings → selection rules

Represents a multiplet of (p,q)



by $$T^{\overbrace{ijk\ldots}^{q}}_{\underbrace{lmn\ldots}_{p}} \qquad (ijk\ldots = 1,2,3)$$

$$T^{ijk\ldots}_{lmp\ldots} = T^{jik\ldots}_{lmp\ldots} \;;\; \text{symmetric in upper indices}$$

$$T^{ijk\ldots}_{lmp\ldots} = T^{ijk\ldots}_{mlp\ldots};\; \text{symmetric in lower indices}$$

$$T^{ijk\ldots}_{lmk\ldots} = 0; \quad \text{traceless}$$

$$1: \ S$$

$$8: O_i^j$$

$$8 = 3 \times 3 - 1$$

$$10: D_{ijk}$$

$$\overline{10}: D^{ijk}$$

$$27: T_{ij}^{lm}$$

$$27 = 6 \times 6 - 9$$

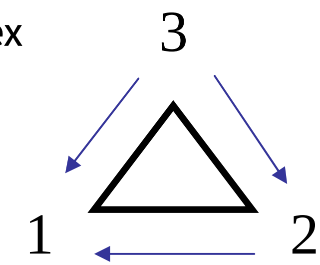
$$35: T_{ijlm}^{k}$$

$$35 = 15 \times 3 - 10$$

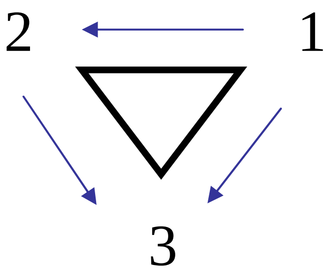
Identifying pentaquarks with tensor notation is useful to construct SU(3) lagrangian and mass relations

How to assign each tensor to a state in a weight diagram ?

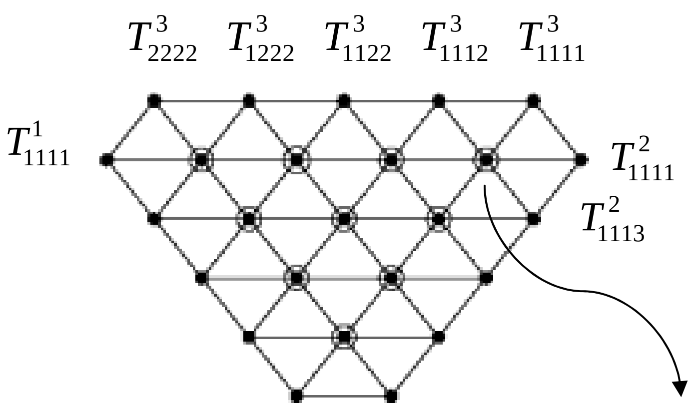
Upper index



Lower index



Example: 35-plet case



T^1_{1111}, T^2_{1112} and T^3_{1113}

assign T^3_{1113} a pure I=3/2 member

and T^1_{1111}, T^2_{1112} are mixture of I=5/2,I=3/2

Identifying the tensors with pentaquarks

For flavor w.f. and overall normalization, see hep-ph/0405010

Octet

$$P^3_1 = N_8^+,\qquad P^3_2 = N_8^0,\qquad P^2_1 = \Sigma_8^+,$$
$$P^1_2 = \Sigma_8^-,\qquad P^1_1 = 1/\sqrt{2}\Sigma_8^0 + 1/\sqrt{6}\Lambda_8^0,\qquad P^2_2 = -1/\sqrt{2}\Sigma_8^0 + 1/\sqrt{6}\Lambda_8^0,$$
$$P^3_3 = -\sqrt{2/3}\Lambda_8^0,\qquad P^2_3 = \Xi_8^0,\qquad P^1_3 = -\Xi_8^-.$$

Decuplet

$$D_{111} = \sqrt{6}\Delta_{10}^{++},\qquad D_{112} = \sqrt{2}\Delta_{10}^{+},\qquad D_{122} = \sqrt{2}\Delta_{10}^{0},$$
$$D_{222} = \sqrt{6}\Delta_{10}^{-},\qquad D_{113} = \sqrt{2}\Sigma_{10}^{+},\qquad D_{123} = -\Sigma_{10}^{0},$$
$$D_{223} = -\sqrt{2}\Sigma_{10}^{-},\qquad D_{133} = \sqrt{2}\Xi_{10}^{0},\qquad D_{233} = \sqrt{2}\Xi_{10}^{-},$$
$$D_{333} = -\sqrt{6}\Omega_{10}^{-}.$$

Anti-decuplet

$$T^{111} = \sqrt{6}\Xi^{--}_{\overline{10},3/2},\qquad T^{112} = -\sqrt{2}\Xi^{-}_{\overline{10},3/2},\qquad T^{122} = \sqrt{2}\Xi^{0}_{\overline{10},3/2},$$
$$T^{222} = -\sqrt{6}\Xi^{+}_{\overline{10},3/2},\qquad T^{113} = \sqrt{2}\Sigma^{-}_{\overline{10}},\qquad T^{123} = -\Sigma^{0}_{\overline{10}},$$
$$T^{223} = -\sqrt{2}\Sigma^{+}_{\overline{10}},\qquad T^{133} = \sqrt{2}N^{0}_{\overline{10}},\qquad T^{233} = -\sqrt{2}N^{+}_{\overline{10}},$$
$$T^{333} = \sqrt{6}\Theta^{+}.$$

27-plet

- $Y = 2, I = 1$

$$T^{33}_{11} = -2\Theta_1^{++},\qquad T^{33}_{12} = \sqrt{2}\Theta_1^{+},\qquad T^{33}_{22} = 2\Theta_1^{0},$$

- $Y = 1, I = 3/2, 1/2$

$$T^{23}_{11} = -\sqrt{2}\Delta_{27}^{++},\qquad T^{13}_{11} = \sqrt{\frac{2}{3}}\Delta_{27}^{+} + \sqrt{\frac{8}{15}}N_{27}^{+},\qquad T^{23}_{12} = -\sqrt{\frac{2}{3}}\Delta_{27}^{+} + \sqrt{\frac{2}{15}}N_{27}^{+},$$
$$T^{33}_{13} = -\sqrt{\frac{6}{5}}N_{27}^{+},\qquad T^{13}_{12} = \sqrt{\frac{2}{3}}\Delta_{27}^{0} + \sqrt{\frac{2}{15}}N_{27}^{0},\qquad T^{23}_{22} = -\sqrt{\frac{2}{3}}\Delta_{27}^{0} + \sqrt{\frac{8}{15}}N_{27}^{0},$$
$$T^{33}_{23} = -\sqrt{\frac{6}{5}}N_{27}^{0},\qquad T^{13}_{22} = \sqrt{2}\Delta_{27}^{-},$$

35 - plet

- $Y = 2, I = 2$

$$T^3_{1111} = 2\sqrt{6}\Theta_2^{+++}, \qquad T^3_{1112} = \sqrt{6}\Theta_2^{++}, \qquad T^3_{1122} = 2\Theta_2^{+},$$
$$T^3_{1222} = \sqrt{6}\Theta_2^{0}, \qquad T^3_{2222} = 2\sqrt{6}\Theta_2^{-},$$

- $Y = 1, I = 5/2, 3/2$

$$T^2_{1111} = -2\sqrt{6}\Delta_{5/2}^{+++}, \qquad T^1_{1111} = 2\sqrt{\frac{6}{5}}\Delta_{5/2}^{++} + \frac{4}{\sqrt{5}}\Delta_{35}^{++},$$
$$T^2_{1112} = -2\sqrt{\frac{6}{5}}\Delta_{5/2}^{++} + \frac{1}{\sqrt{5}}\Delta_{35}^{++}, \qquad T^3_{1113} = -\sqrt{5}\Delta_{35}^{++},$$
$$T^1_{1112} = 2\sqrt{\frac{3}{5}}\Delta_{5/2}^{+} + \sqrt{\frac{3}{5}}\Delta_{35}^{+}, \qquad T^2_{1122} = -2\sqrt{\frac{3}{5}}\Delta_{5/2}^{+} + \frac{2}{\sqrt{15}}\Delta_{35}^{+},$$
$$T^3_{1123} = -\sqrt{\frac{5}{3}}\Delta_{35}^{+}, \qquad T^1_{1122} = 2\sqrt{\frac{3}{5}}\Delta_{5/2}^{0} + \frac{2}{\sqrt{15}}\Delta_{35}^{0},$$
$$T^2_{1222} = -2\sqrt{\frac{3}{5}}\Delta_{5/2}^{0} + \sqrt{\frac{3}{5}}\Delta_{35}^{0}, \qquad T^3_{1223} = -\sqrt{\frac{5}{3}}\Delta_{35}^{0},$$
$$T^1_{1222} = 2\sqrt{\frac{6}{5}}\Delta_{5/2}^{-} + \frac{1}{\sqrt{5}}\Delta_{35}^{-}, \qquad T^2_{2222} = -2\sqrt{\frac{6}{5}}\Delta_{5/2}^{-} + \frac{4}{\sqrt{5}}\Delta_{35}^{-},$$
$$T^3_{2223} = -\sqrt{5}\Delta_{35}^{-}, \qquad T^1_{2222} = 2\sqrt{6}\Delta_{5/2}^{--}$$

etc

- The phases are chosen to be consistent with de Swart convention.

J.J. de Swart, RMP 35, 916 (1963)

SU(3) Lagrangian in the tensor method

Under SU(3) transformation, quarks (and antiquarks) transform

$$q_i \xrightarrow{SU(3)} U_i^{\ j} q_j , \quad \bar{q}^i = q_i^* \to U_i^{*j} q_j^* = U^{+i}{}_j \bar{q}^j$$

Upper indices transform with U^+

Lower indices transform with U

$$\text{Ex. } B_j^i \to U_j^{\ k} U^{+i}{}_l B_k^l , \quad \bar{B}_i^{\ j} = B_j^{*i} \to U_j^{*k} U_l^{\mathrm{T}i} B_k^{*l} = U^{+j}{}_k U_i^{\ l} \bar{B}_l^{\ k}$$

SU(3) symmetric Lagrangian should be invariant under SU(3) transformation→ SU(3) singlet.

The only way to form a SU(3) invariant is to have "upper and lower indices fully contracted" !!

→ yields selection rules

Recipe: Write Lagrangian in terms of all possible tensors and multiply $\delta_i^j, \varepsilon_{ijk}$ in all possible ways to form fully contracted terms

$$ex: 8_5 - 8_3 - 8_3 : \quad (d+f)\bar{P}_i^{\ l} B_k^i M_l^{\ k} + (d-f)\bar{P}_i^{\ l} B_l^k M_k^{\ i} + (\text{h.c.})$$

Mass relations

→ Need to include SU(3) breaking in $O(m_q)$

QCD mass terms

Note, isospin is assumed to be a good symmetry, $m_u = m_d$

$$M_{QCD} = \overline{q}\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & m_s \end{pmatrix} q \xrightarrow{m_u = m_d} a\, \overline{q}^i q_i + b\, \overline{q}^i Y_i^{\ j} q_j$$

$$\text{where } Y_i^{\ j} = \frac{1}{3}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

SU(3) breaking mass

Symmetry breaking hypothesis: The breaking in the leading order transforms like hypercharge Y . In practice it means that the mass terms are obtained by fully contracting indices including Y.

→ It only counts the net hypercharge and leads to the usual GMO relation.

We have constructed SU(3) interaction for the following three cases (see hep-ph/0405010 by Oh and Kim).

Set 1. Pentaquark - normal baryon octet – meson octet

Set 2. Pentaquark - normal baryon decuplet – meson octet

Set 3. Pentaquark - pentaquark – meson octet

provide selection rules for all the pentaquarks → could be useful for reaction mechanisms.

$$\text{Ex.}\ \ 35_5 - 10_3 - 8_3 :\ \overline{T}_a^{ijkl} D_{ijk} M_l^a + (\text{h.c.})$$

$$10_5 - 8_3 - 8_3 :\ \varepsilon_{ijk} \overline{D}^{jlm} B_l^i M_m^k + (\text{h.c.})$$

Also the mass relations within a multiplet were obtained.

$$M_8 = a\overline{P}^i_j P_i^j + b\overline{P}^i_j Y_i^m P_m^j + c\overline{P}^i_j Y_m^j P_i^m$$

$$M_{10} = a\overline{D}^{ijk} D_{ijk} + b\overline{D}^{ijk} Y_k^m D_{ijm}$$

$$M_{\overline{10}} = a\overline{T}_{ijk} T^{ijk} + b\overline{T}_{ijk} Y_m^k T^{ijm}$$

$$M_{27} = a\overline{T}^{ij}_{kl} T_{ij}^{kl} + b\overline{T}^{ij}_{kl} Y_m^l T_{ij}^{km} + c\overline{T}^{ij}_{kl} Y_j^m T_{im}^{kl}$$

$$M_{35} = a\overline{T}_i^{jklm} T_{jklm}^i + b\overline{T}_i^{jklm} Y_j^n T_{klmn}^i + c\overline{T}_i^{jklm} Y_n^i T_{jklm}^n$$

Some of the results in hep-ph/0405010

1. If Θ is isotriplet, there should be the decay channels

$$\Theta_1^{++} \to pK^+, \Theta_1^0 \to nK^0$$

2. If Θ is isotriplet or isotensor, there should be the channels if kinematically allowed

$$\Theta_1, \Theta_2 \to K\Delta$$

3. The members in 35-plet can be measured in 10-8 decay. If X in 35-plet exists, it can be observed in a unique decay mode

$$X^-(X^{--}) \to \overline{K}^0\Omega^-(K^-\Omega^-)$$

4. 27-27-8, 35-35-8 have two types interactions

$$27_5 - 27_5 - 8_3: \ (d+f)\overline{T}_{ij}^{kl} T_{km}^{ij} M_l^m + (d-f)\overline{T}_{ij}^{kl} T_{kl}^{im} M_m^j$$

$$35_5 - 35_5 - 8_3: \ (d+f)\overline{T}_a^{ijkl} T_{ijkm}^a M_l^n + (d-f)\overline{T}_a^{ijkl} T_{ijkl}^m M_m^a$$

5. 10-10bar-8, 35-8-8, 35-10bar-8 are not allowed

5. In addition to GMO relation for octet and ESR for 10 and 10bar, we have

$$2(N_{27}+\Xi_{27})=3\Lambda_{27}+\Sigma_{27}$$

$$\Omega_{27,1}-\Xi_{27,3/2}=\Xi_{27,3/2}-\Sigma_{27,2}$$

$$\Sigma_{27,2}-\Delta_{27}=\Delta_{27}-\Theta_{1}$$

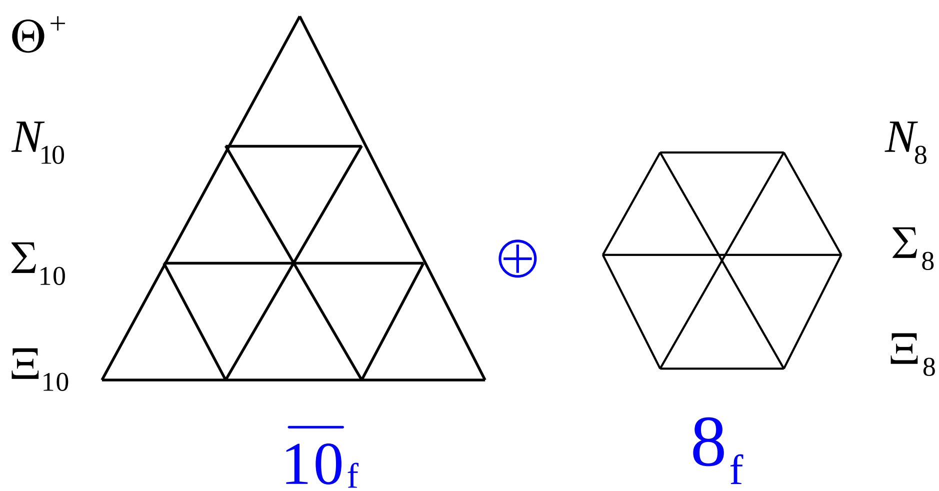
$$\Omega_{35}-\Xi_{35}=\Xi_{35}-\Sigma_{35}=\Sigma_{35}-\Delta_{35}=\Delta_{35}-\Theta_{2}$$

$$X-\Omega_{35,1}=\Omega_{35,1}-\Xi_{35,3/2}=\Xi_{35,3/2}-\Sigma_{35,2}-\Delta_{5/2}$$

Pentaquarks in Jaffe and Wilczek model

Jaffe and Wilczek PRL(2003) view the pentaquarks as diquark-diquark-antiquark $q^2q^2\bar{q}$ where q^2(boson) is assumed be $\bar{3}_c,\ \bar{3}_f$ $(\because\ q^2 \simeq \bar{q})$

$$q^2q^2 \otimes \bar{q} \qquad \bar{6}_f \otimes \bar{3}_f = \overline{10}_f \oplus 8_f$$



Pentaquarks belonging to antidecuplet and octet in this picture!!

Ideal mixing

Note
$$N^{+}_{\overline{10}} = \frac{1}{\sqrt{3}}\left([ud][ud]\bar{d} + \sqrt{2}[ud][us]\bar{s}\right)$$
$$N^{+}_{8} = \frac{1}{\sqrt{3}}\left(-\sqrt{2}[ud][ud]\bar{d} + [ud][us]\bar{s}\right)$$

Symmetry breaking hypothesis for the mass splitting counts only the net hypercharge. More realistically one needs to count the $\bar{s}s$ number in the mass splitting ➔ separate $\bar{s}s$ component

8_f and 10_f mixing is necessary in order to arrange the states according to $\delta M = \gamma\left(n_s + n_{\bar{s}}\right)$ → Ideal mixing

$$N_{\overline{10}} = \sqrt{\frac{1}{3}}N_q + \sqrt{\frac{2}{3}}N_s, \quad N_8 = \sqrt{\frac{2}{3}}N_q - \sqrt{\frac{1}{3}}N_s,$$
$$\Sigma_{\overline{10}} = \sqrt{\frac{2}{3}}\Sigma_q + \sqrt{\frac{1}{3}}\Sigma_s, \quad \Sigma_8 = \sqrt{\frac{1}{3}}\Sigma_q - \sqrt{\frac{2}{3}}\Sigma_s,$$

diagonalizing the Hamiltonian in the basis $N_q, N_s (\Sigma_q, \Sigma_s)$

Mass relations in J&W model

8 masses and 5 parameters
(2 in antidecuplet and 3 in octet) $\longrightarrow$ 3 parameter free relations

$$M_{N_q} + 2M_{N_s} = 2M_\Theta + M_{\Xi_{10}},$$
$$2M_{\Sigma_q} + M_{\Sigma_s} = M_\Theta + 2M_{\Xi_{10}},$$
$$3M_{\Lambda_8} = M_{\Sigma_q} + M_{N_q} + 2M_{\Xi_8} - M_{\Xi_{10}}.$$

Inputs: $M_\Theta = 1540$ MeV $M_{\Xi_{3/2}} = 1862$ MeV

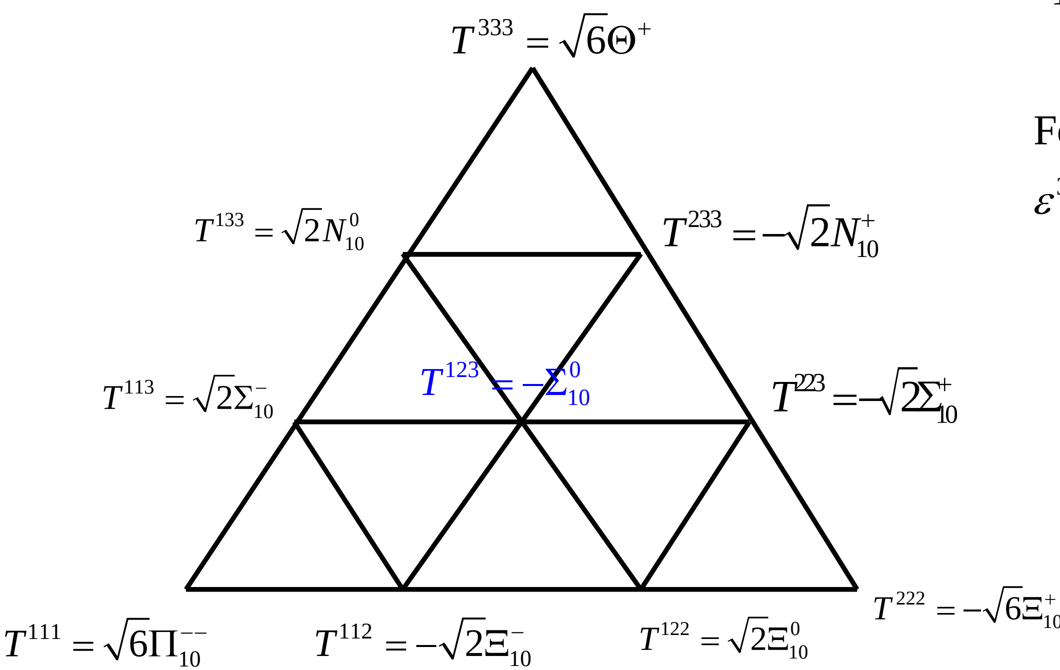
- **$M(\Xi_8) = M(\Xi_{10})$ and N_q = N(1440) Roper resonance: this gives $M(N_s) = 1751$,**
- **$M(\Lambda_8) = M(\Sigma_q)$: this gives $M(\Lambda_8) = M(\Sigma_q) = 1651$ and $M(\Sigma_s) = 1962$ MeV**

Selection rules for the antidecuplet pentaquark

$$\overline{10}: \ T^{ijk}$$

$$\overline{10}_5 - 8_3 - 8_3 \ \text{Lagragian}$$

$$-g_{\overline{10}} \ \varepsilon^{klm} \overline{T}_{ijk} M^i_l B^j_m$$



For Θ^+:

$$\varepsilon^{3lm}\overline{T}_{333}M^3_l B^3_m = \overline{T}_{333}M^3_1 B^3_2 - \overline{T}_{333}M^3_2 B^3_1$$
$$= \sqrt{6}\overline{\Theta}^+ K^+ n - \sqrt{6}\overline{\Theta}^+ K^0 p$$

Similarly goes through for the other particles.

decay modes that can be used to identify pentaquarks belonging to $\overline{10}$

Oh,Kim,Lee, PRD(2004)

Θ^+		$N^+_{\overline{10}}$		$N^0_{\overline{10}}$		$\Sigma^+_{\overline{10}}$	
K^+n	$\sqrt{6}$	π^+n	$-\sqrt{2}$	π^0n	1	$\pi^+\Lambda$	$-\sqrt{3}$
K^0p	$-\sqrt{6}$	π^0p	-1	π^-p	$-\sqrt{2}$	$\pi^+\Sigma^0$	1
		η_8p	$\sqrt{3}$	η_8n	$\sqrt{3}$	$\pi^0\Sigma^+$	-1
		$K^+\Lambda$	$-\sqrt{3}$	$K^+\Sigma^-$	$\sqrt{2}$	$\eta_8\Sigma^+$	$\sqrt{3}$
		$K^+\Sigma^0$	1	$K^0\Lambda$	$-\sqrt{3}$	$K^+\Xi^0$	$\sqrt{2}$
		$K^0\Sigma^+$	$\sqrt{2}$	$K^0\Sigma^0$	-1	$\bar{K}^0p$	$-\sqrt{2}$
$\Sigma^0_{\overline{10}}$		$\Sigma^-_{\overline{10}}$		$\Xi^+_{\overline{10}}$		$\Xi^0_{\overline{10}}$	
$\pi^+\Sigma^-$	-1	$\pi^0\Sigma^-$	1	$\pi^+\Xi^0$	$\sqrt{6}$	$\pi^+\Xi^-$	$\sqrt{2}$
$\pi^0\Lambda$	$-\sqrt{3}$	$\pi^-\Lambda$	$-\sqrt{3}$	$\bar{K}^0\Sigma^+$	$-\sqrt{6}$	$\pi^0\Xi^0$	-2
$\pi^-\Sigma^+$	1	$\pi^-\Sigma^0$	-1			$\bar{K}^0\Sigma^0$	2
$\eta_8\Sigma^0$	$\sqrt{3}$	$\eta_8\Sigma^-$	$\sqrt{3}$			$K^-\Sigma^+$	$\sqrt{2}$
$K^+\Xi^-$	-1	$K^0\Xi^-$	$-\sqrt{2}$				
$K^0\Xi^0$	-1	K^-n	$-\sqrt{2}$				
$\bar{K}^0n$	1						
K^-p	-1						
$\Xi^-_{\overline{10}}$		$\Xi^{--}_{\overline{10}}$					
$\pi^0\Xi^-$	-2	$\pi^-\Xi^-$	$-\sqrt{6}$				
$\pi^-\Xi^0$	$-\sqrt{2}$	$K^-\Sigma^-$	$-\sqrt{6}$				
$\bar{K}^0\Sigma^-$	$\sqrt{2}$						
$K^-\Sigma^0$	-2						

Selection rules for the octet pentaquark

$$\overline{6}_f \otimes \overline{3}_f = \overline{10}_f \oplus 8_f$$

k: index for the antiquark

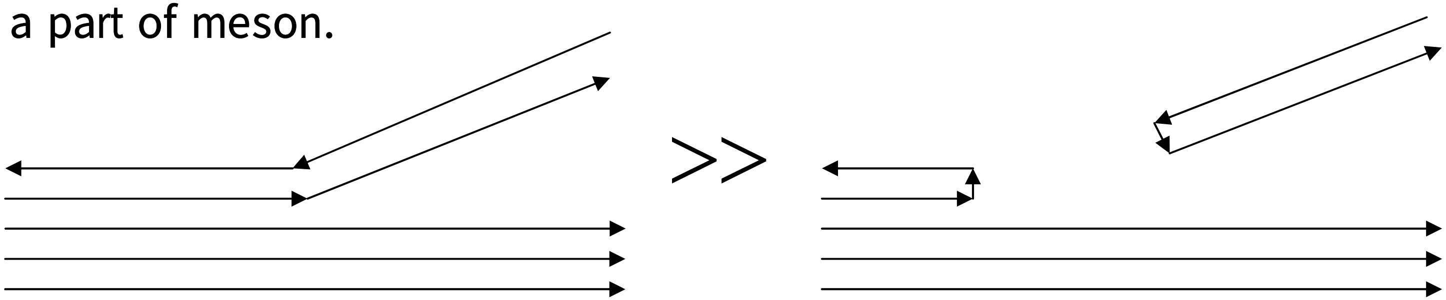
$$S^{ij} \otimes \overline{q}^k = T^{ijk} \oplus S^{[ij,k]}$$

Being an octet representation, one can write

$$S^{[ij,k]} = \varepsilon^{ljk} P_l^i + \varepsilon^{lik} P_l^j \qquad \text{sym in } i, j$$

Fall-apart mechanism (or generalized OZI rule): in the decay to meson and baryon, the anti-quark should be a part of meson.

Close and Dudek
(or Lee,Kim,Oh)



$8_5 - 8_3 - 8_3$ Lagrangian

$f/d = 1/3$ in the OZI rule

$$g_8 \varepsilon^{ilm} \overline{S}_{[ij,k]} B_l^j M_m^k + \text{h.c.} = 2 g_8 \overline{P}_i^m B_i^l M_m^l + g_8 \overline{P}_i^m B_m^l M_l^i + \text{h.c.}$$

Ξ_8^-		Ξ_8^0		N_8^+		N_8^0	
$\pi^-\Xi^0$	-1	$\pi^+\Xi^-$	-1	$\pi^0 p$	$\sqrt{2}$	$\pi^0 n$	$-\sqrt{2}$
$\pi^0\Xi^-$	$\frac{1}{\sqrt{2}}$	$\pi^0\Xi^0$	$-\frac{1}{\sqrt{2}}$	$\pi^+ n$	2	$\pi^- p$	2
$\eta_8\Xi^-$	$-\sqrt{\frac{3}{2}}$	$\eta_8\Xi^0$	$-\sqrt{\frac{3}{2}}$	$\eta_8 p$	0	$\eta_8 n$	0
$\bar{K}^0\Sigma^-$	-2	$K^-\Sigma^+$	2	$K^+\Sigma^0$	$\frac{1}{\sqrt{2}}$	$K^0\Sigma^0$	$-\frac{1}{\sqrt{2}}$
$K^-\Sigma^0$	$-\sqrt{2}$	$\bar{K}^0\Sigma^0$	$-\sqrt{2}$	$K^0\Sigma^+$	1	$K^+\Sigma^-$	1
$K^-\Lambda$	0	$\bar{K}^0\Lambda$	0	$K^+\Lambda$	$-\sqrt{\frac{3}{2}}$	$K^0\Lambda$	$-\sqrt{\frac{3}{2}}$

Σ_8^0		Σ_8^+		Σ_8^-		Λ_8^0	
$\pi^+\Sigma^-$	$\frac{1}{\sqrt{2}}$	$\pi^+\Sigma^0$	$-\frac{1}{\sqrt{2}}$	$\pi^-\Sigma^0$	$\frac{1}{\sqrt{2}}$	$\pi^-\Sigma^+$	$\sqrt{\frac{3}{2}}$
$\pi^-\Sigma^+$	$-\frac{1}{\sqrt{2}}$	$\pi^0\Sigma^+$	$\frac{1}{\sqrt{2}}$	$\pi^0\Sigma^-$	$-\frac{1}{\sqrt{2}}$	$\pi^+\Sigma^-$	$\sqrt{\frac{3}{2}}$
$\pi^0\Lambda$	$\sqrt{\frac{3}{2}}$	$\eta_8\Sigma^+$	$\sqrt{\frac{3}{2}}$	$\eta_8\Sigma^-$	$\sqrt{\frac{3}{2}}$	$\pi^0\Sigma^0$	$\sqrt{\frac{3}{2}}$
$\eta_8\Sigma^0$	$\sqrt{\frac{3}{2}}$	$\pi^+\Lambda$	$\sqrt{\frac{3}{2}}$	$\pi^-\Lambda$	$\sqrt{\frac{3}{2}}$	$\eta_8\Lambda$	$-\sqrt{\frac{3}{2}}$
$K^- p$	$\frac{1}{\sqrt{2}}$	$K^+\Xi^0$	2	$K^0\Xi^-$	-2	$K^+\Xi^-$	0
$\bar{K}^0 n$	$-\frac{1}{\sqrt{2}}$	$\bar{K}^0 p$	1	$K^- n$	1	$K^0\Xi^0$	0
$K^+\Xi^-$	$-\sqrt{2}$					$K^- p$	$-\sqrt{\frac{3}{2}}$
$K^0\Xi^0$	$-\sqrt{2}$					$\bar{K}^0 n$	$-\sqrt{\frac{3}{2}}$

Note, some of the decay modes are not allowed by ``the OZI rule''.

Justification for the generalized OZI rule ?? Ideal mixing

$$\left\langle [ud][ud]\bar{d} \,|\, H \,|\, [ud][us]\bar{s} \right\rangle = 0$$

The generalized OZI rule leads to ideal mixing and fall-apart mechanism

Note, $\Theta^+ \to KN$ occurs through the fall-apart mechanism. The small width experimentally observed indicates that the fall-apart decay gives small width for the octet pentaquarks

Decay modes in the ideal mixing

$N^+_{\bar{q}q}$		$N^+_{\bar{s}s}$		$N^0_{\bar{q}q}$		$N^0_{\bar{s}s}$	
$\pi^+ n$	$-\sqrt{6}$	$K^+\Lambda$	$-\frac{3}{\sqrt{2}}$	$\pi^0 n$	$\sqrt{3}$	$K^0\Sigma^0$	$-\sqrt{\frac{3}{2}}$
$\pi^0 p$	$-\sqrt{3}$	$K^+\Sigma^0$	$\sqrt{\frac{3}{2}}$	$\pi^- p$	$-\sqrt{6}$	$K^+\Sigma^-$	$\sqrt{3}$
$\eta_{\bar{q}q} p$	$\sqrt{3}$	$K^0\Sigma^+$	$\sqrt{3}$	$\eta_{\bar{q}q}$	$\sqrt{3}$	$K^0\Lambda$	$-\frac{3}{\sqrt{2}}$
		$\eta_{\bar{s}s} p$	$-\sqrt{3}$			$\eta_{\bar{s}s} n$	$-\sqrt{3}$
$\Sigma^+_{\bar{q}q}$		$\Sigma^+_{\bar{s}s}$		$\Sigma^-_{\bar{q}q}$		$\Sigma^-_{\bar{s}s}$	
$\pi^+\Sigma^0$	$\sqrt{\frac{3}{2}}$	$K^+\Xi^0$	$\sqrt{6}$	$\pi^-\Sigma^0$	$-\sqrt{\frac{3}{2}}$	$K^0\Xi^-$	$-\sqrt{6}$
$\pi^0\Sigma^+$	$-\sqrt{\frac{3}{2}}$	$\eta_{\bar{s}s}\Sigma^+$	$-\sqrt{6}$	$\pi^0\Sigma^-$	$\sqrt{\frac{3}{2}}$	$\eta_{\bar{s}s}\Sigma^-$	$-\sqrt{6}$
$\eta_{\bar{q}q}\Sigma^+$	$\sqrt{\frac{3}{2}}$			$\eta_{\bar{q}q}\Sigma^-$	$\sqrt{\frac{3}{2}}$		
$\pi^+\Lambda$	$-\frac{3}{\sqrt{2}}$			$\pi^-\Lambda$	$-\frac{3}{\sqrt{2}}$		
$\bar{K}^0 p$	$-\sqrt{3}$			$K^- n$	$-\sqrt{3}$		
$\Sigma^0_{\bar{q}q}$		$\Sigma^0_{\bar{s}s}$					
$\pi^+\Sigma^-$	$-\sqrt{\frac{3}{2}}$	$K^+\Xi^-$	$-\sqrt{3}$				
$\pi^-\Sigma^+$	$\sqrt{\frac{3}{2}}$	$K^0\Xi^0$	$-\sqrt{3}$				
$\eta_{\bar{q}q}\Sigma^0$	$\sqrt{\frac{3}{2}}$	$\eta_{\bar{s}s}\Sigma^0$	$-\sqrt{6}$				
$\pi^0\Lambda$	$-\frac{3}{\sqrt{2}}$						
$K^- p$	$-\sqrt{\frac{3}{2}}$						
$\bar{K}^0 n$	$\sqrt{\frac{3}{2}}$						

To separate $\bar{q}q$ and $\bar{s}s$ in meson sector we introduce

$$-\sqrt{3}g_1\eta_1\bar{P}_i^{\,j}B_j^i+(\text{h.c.})$$

Summary

1. In SU(3) quark model, totally 91 states in 1,8,10,10bar,27, 35.
2. We constructed selection rules for pentaquark decay and mass relations in the tensor notation → could be useful for pentaquark search
3. X in 35-plet has a unique decay mode to be searched in expts.
4. Selection rules for J&W pentaquark and mass relations are also presented.