Meson-Baryon s–wave Resonances with Strangeness –3

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Abstract. Starting from a consistent SU(6) extension of the Weinberg-Tomozawa (WT) meson-baryon chiral Lagrangian (Phys. Rev. **D74** (2006) 034025), we study the s–wave meson-baryon resonances in the strangeness $S = -3$ and negative parity sectors. Those resonances are generated by solving the Bethe–Salpeter equation with the WT interaction used as kernel. The considered mesons are those of the **35**-SU(6)-plet, which includes the pseudoscalar (PS) octet of pions and the vector (V) nonet of the rho meson. For baryons we consider the **56**-SU(6)-plet, made of the $1/2^+$ octet of the nucleon and the $3/2^+$ decuplet of the Delta. Quantum numbers $I(J^P) = 0(3/2^-)$ are suggested for the experimental resonances $\Omega^*(2250)^-$ and $\Omega^*(2380)^-$. Among other, resonances with $I = 1$ are found, which minimal quark content is $sss\bar{l}l'$, being s the *strange* quark and l, l' any of the the light *up* or *down* quarks. A clear signal for such a pentaquark would be a baryonic resonance with strangeness -3 and electric charge of -2 or 0, in proton charge units. We suggest looking for $K^-\Xi^-$ resonances with masses around 2100 and 2240 MeV in the sector $1(1/2^-)$, and for $\pi^\pm\Omega^-$ and $K^-\Xi^{*-}$ resonances with masses around 2260 MeV in the sector $1(3/2^-)$.

PACS. 11.30.Hv Flavor symmetries – 11.30.Ly Other internal and higher symmetries – 11.10.St Bound and unstable states; Bethe–Salpeter equations – 11.30.Rd Chiral symmetries – 11.80.Gw Multichannel scattering

1 Introduction

Using a spin-flavor-SU(6) extended Weinberg-Tomozawa (WT) meson-baryon interaction[1] [1], we study the s-wave resonances with strangeness $S = -3$, isospin I=0, 1 and spin-parity $J^P = 1/2^-$, $3/2^-$, $5/2^-$. The resonances are generated by solving the Bethe–Salpeter equation with the extended WT meson-baryon interaction used as a kernel. In this model, the involved mesons are those of the **35**-SU(6)-plet=$8_1 \oplus 8_3 \oplus 1_3$, which includes the PS meson octet of the pions, $(\pi, \eta, K, \bar{K}) \in 8_1$ and the V nonet of the rho meson, $(\rho, \omega, \phi, K^*, \bar{K}^*) \in 8_3 \oplus 1_3$. We approximate the η meson as the isospin singlet state of the PS SU(3)-octet. For the ω and ϕ vector mesons, we assume ideal mixing among the V singlet and octet mesons. The baryons are those of the **56**-SU(6)-plet=$8_2 \oplus 10_4$, which contains the $1/2^+$ octet of the N $(N, \Lambda, \Sigma, \Xi)$ and the $3/2^+$ decuplet of the Δ $(\Delta, \Sigma^*, \Xi^*, \Omega)$. Masses, widths and couplings of the resonances found are calculated and, when possible, comparison with experimental ones is attempted.

Unitary extensions of chiral perturbation theory to study meson-baryon interactions using a coupled channel scheme were introduced some time ago [3]. They have been successfully applied in the theoretical microscopical description of meson-baryon scattering and of well

known lowest lying baryon resonances, which were shown to be dynamically generated. Thus different $J^P = 1/2^-$ s–wave resonances ($\subset 8_\pi \times 8_N$, made of PS mesons of the pion octet and of the baryons of the nucleon octet) like $N^*(1535)$, $\Lambda(1405)$, $\Lambda(1670)$, $\Sigma(1620)$ and $\Xi(1620)$ [4] and, more recently, the $J^P = 3/2^-$ d–wave resonances ($\subset 8_\pi \times 10_\Delta$, made of PS mesons of the pion octet and of the baryons of the delta decuplet) like $\Lambda(1520)$, $\Sigma(1670)$ and $\Xi(1820)$ [5] have been found and their properties studied. Those previous chiral Bethe-Salpeter coupled channels unitary approaches using the WT kernel have included hadron multiplets belonging to the flavor SU(3) irreducible representations. In the case of mesons, the only ingredient has been the octet of PS mesons.

2 Model

Motivations for extending the previous SU(3) based models to a SU(6) extended model are the following. First, in the large N_c limit, 8_N and 10_Δ are degenerated and form a 56-multiplet of spin–flavor SU(6). Second, vector mesons do exist, interact and couple to baryons. Third, there are baryonic resonances decaying to a PS meson and a baryon, but also to a V meson and a baryon, for instance, the strangeness –3 resonance $\Omega^*(2380)^-$ decays to $K^-\Xi^{*0}$ and to $\bar{K}^{*0}\Xi^-$ with similar strengths and of the same order as the other known decay mode $(\bar{K}^-\pi^0\Xi^-)$ [8]. All of these call for a 'SU(6)' model which deals all together with

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the 56-baryons and 35-mesons like that of ref.[1]. We consider this spin–flavor symmetric scenario as a reasonable first approach. In the 'SU(6)' approach the interacting kernel V^{IYJ} for a sector with hypercharge Y (strangeness plus one for baryons), isospin I and spin J is given by:

$$\langle m_i, \ B_i | V^{IYJ}(s) | m_j, \ B_j \rangle = D_{ij}^{IYJ} \ \frac{2\sqrt{s} - M_{B_i} - M_{B_j}}{4 f^2}$$

$$m_i, m_j \in \mathbf{35}, \ B_i, B_j \in \mathbf{56}, \quad D^{IYJ} = \sum_\nu \bar{\lambda}_\nu \ \hat{P}_\nu^{IYJ}$$

$$\bar{\lambda}_{\mathbf{56}} = -12, \ \bar{\lambda}_{\mathbf{70}} = -18, \quad \bar{\lambda}_{\mathbf{700}} = 6, \ \bar{\lambda}_{\mathbf{1134}} = -2,$$

$\hat{P}_\nu^{IYJ}$ is the projector of the meson-baryon into the ν–SU(6)-representation, and ν runs over $\mathbf{56}$, $\mathbf{70}$, $\mathbf{700}$, $\mathbf{1134}$ because $\mathbf{35} \otimes \mathbf{56} = \mathbf{56} \oplus \mathbf{70} \oplus \mathbf{700} \oplus \mathbf{1134}$.
The $\bar{\lambda}_\nu$ positive (negative) means that in channel ν the meson-baryon interaction is repulsive (attractive). When this kernel is restricted to m_i, m_j being only PS mesons, it coincides with the 'SU(3)' lowest order WT kernels previously used in refs.[4,5].
Note that D is SU(6) invariant, this symmetry being explicitly broken by the different masses of baryons and mesons. In addition we replace the f^2 of the interaction by $f_{m_i} f_{m_j}$ for the ij matrix element. We use $f_\pi = 92.4$ MeV, $f_K = 1.15 f_\pi$, $f_\eta = 1.2 f_\pi$ [7], and $f_{K^*} = f_K$, $f_\rho = f_\pi$, $f_\omega = f_\phi = f_\eta$. This interaction is used to solve the Bethe–Salpeter coupled channel equation for the meson-baryon T−matrix

$$T^{-1}(s) \ = \ V^{-1}(s) \ - \ J(s) \qquad (1)$$

where $J(s)$ is the diagonal matrix of the meson-baryon loop functions [4,5]. For each channel (m_i, B_i) it is ultra-violet regularized by subtracting a constant so that $J\left(s = m_{m_i}^2 + M_{B_i}^2\right) = 0$.
We test that the inclusion of the new 'SU(6)' channels (those involving V mesons not included in the 'SU(3)' calculations) does not spoil previous results which were successful. See ref. [6] for comparison in the sector $(S = -1, \ I = 0, \ J^P = 1/2^-)$.

3 Results

We solve the coupled–channel Bethe–Salpeter equation and look for the T−matrix poles in the second Riemann sheet. Close to a pole the T−matrix behaves as

$$T_{ij} \sim \frac{g_i g_j}{\sqrt{s} - (M_R - i\Gamma_R/2)} \qquad (2)$$

and the position of the pole and its residue define the mass M_R, width Γ_R and complex coupling constants g_i to different i channels of the found resonance.

All the calculations are done neglecting the widths of the baryons of the decuplet and of the V mesons. When the orbital angular momentum of the meson-baryon system is zero, the odd parity $S = -3$ resonances formed by coupling $\mathbf{35}$-mesons to $\mathbf{56}$-baryons can have the following $I(J^P)$ quantum numbers: $0(1/2^-)$, $0(3/2^-)$, $0(5/2^-)$,

$1(1/2^-)$, $1(3/2^-)$ and $1(5/2^-)$. The mass, width and absolute values of the coupling constants of the resonances found for each of those sectors are shown in tables 1, 2, 3, 4, 5 and 6, respectively. Resonances with width below 125 MeV are displayed in fig. 1.

Several $(S = -3, I = 1)$ resonances have been found (tables 4, 5 and 6 and full symbols in fig. 1).These resonances have, at least, three s quarks to provide strangeness $S = -3$ and a pair of light (u or d) quark-antiquark to achive isospin $I = 1$ quantum number. Hence, those dynamically generated $(S = -3, I = 1)$ resonances are pentaquarks and in principle they could be empirically spotted very easily. A clear signal of them would be a resonance with strangeness $S = -3$ and electric charge $Q = -2$ (this is $I_z = -1$) with minimal quark content $sssd\bar{u}$. Another clear signature would be a $S = -3$ and $Q = 0$ resonance with a minimal quark content of $sssu\bar{d}$. From the tables, the best ways for observing pentaquarks would be, in the sector $I(J^P) = 1(1/2^-)$ looking for $K^- \Xi^-$ resonances with masses around 2100 and 2240 MeV, and in the sector $I(J^P) = 1(3/2^-)$ looking for $\pi^\pm \Omega^-$ and $K^- \Xi^{*-}$ resonances with masses around 2260 MeV.
All the experimentally known Ω^* resonances are listed in table 7. Tentatively, we identify the experimental isoscalar $\Omega^*(2250)^-$ to the theoretical $\Omega^*(2265)^-$ of sector $0(3/2^-)$, because of the relative closeness of masses and widths and, also, of observed decay channels. Likewise, the experimental $\Omega^*(2380)^-$ could be assigned to the found $\Omega^*(2343)^-$ of sector $0(3/2^-)$. We do not find a clear assignment for the experimental $\Omega^*(2470)$ because it decays to $\Omega^- \pi^+ \pi^-$, and the resonances that we find around that energy have not the possibility of decaying to such channel.
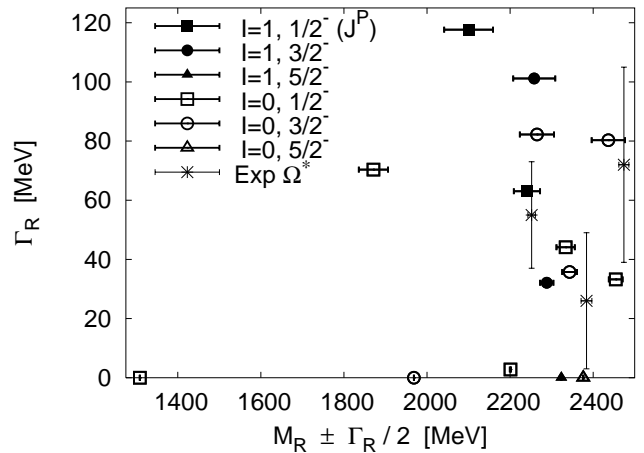
More details will be given elsewhere.

Fig. 1. Spin–parity $J^P = \frac{1}{2}^-$, $\frac{3}{2}^-$ and $\frac{5}{2}^-$ resonance properties in the $I = 0$ (empty symbols) and $I = 1$ (filled symbols), $S = -3$ ($Y = -2$) sectors. The points with error-bars are defined from the masses (M_R) and widths (Γ_R) of the found resonances as $(M_R \pm \Gamma_R/2, \Gamma_R)$. The experimental Ω^* resonance masses and widths with their error bars are from refs. [7,8,9,10]

Table 1. Masses, widths and absolute values of coupling constants for each channel, in the sector $I = 0$, $J^P = 1/2^-$ and $S = -3$. The underlining indicates open channels. 'SU(6)' stands for the full $\mathbf{35 \times 56}$ result. 'SU(3)' for the $\mathbf{8 \times 8}$ result.

M_R [MeV]	Γ_R	$\bar{K}\Xi$	$\bar{K}^*\Xi$	$|g_i|$ $\bar{K}^*\Xi^*$	$\omega\Omega$	$\phi\Omega$
			$I = 0, J^P = 1/2^-$, 'SU(6)'			
1309	00	1.22	0.61	3.27	0.17	5.78
1871	70	<u>1.57</u>	3.63	4.17	1.39	3.23
2201	2.8	<u>0.22</u>	1.63	2.36	0.48	1.38
2334	44	<u>0.76</u>	<u>0.37</u>	0.66	3.44	1.08
2454	33	<u>0.38</u>	<u>0.22</u>	<u>0.97</u>	0.18	4.32
-	-	-				'SU(3)'

Table 2. Same as Table 1 for the sector $I = 0$, $J^P = 3/2^-$.

M_R [MeV]	Γ_R	$\bar{K}\Xi^*$	$\bar{K}^*\Xi$	$\eta\Omega$	$|g_i|$ $\bar{K}^*\Xi^*$	$\omega\Omega$	$\phi\Omega$
				$I = 0, J^P = 3/2^-$, 'SU(6)'			
1969	0	1.78	2.43	2.37	1.44	0.00	2.51
2265	82	<u>1.19</u>	<u>0.34</u>	<u>0.28</u>	3.71	1.21	0.55
2343	36	<u>0.42</u>	<u>0.84</u>	<u>0.04</u>	1.01	3.31	0.16
2437	80	<u>0.07</u>	<u>0.09</u>	<u>1.19</u>	<u>0.12</u>	0.00	4.38
2051	86	<u>1.97</u>		3.34			'SU(3)'

Table 3. Same as Table 1 for the sector $I = 0$, $J^P = 5/2^-$.

M_R [MeV]	Γ_R	$\bar{K}^*\Xi^*$	$|g_i|$ $\omega\Omega$	$\phi\Omega$
			$I = 0, J^P = 5/2^-$, 'SU(6)'	
2376	00	1.41	2.78	0.00

Table 4. Same as Table 1 for the sector $I = 1$, $J^P = 1/2^-$.

M_R [MeV]	Γ_R	$\bar{K}\Xi$	$\bar{K}^*\Xi$	$|g_i|$ $\bar{K}^*\Xi^*$	$\rho\Omega$
			$I = 1, J^P = 1/2^-$, 'SU(6)'		
2100	118	<u>1.47</u>	3.39	1.1	2.1
2241	63	<u>0.88</u>	<u>0.87</u>	1.67	3.87
-	-	-			'SU(3)'

Table 5. Same as Table 1 for the sector $I = 1$, $J^P = 3/2^-$.

M_R [MeV]	Γ_R	$\pi\Omega$	$\bar{K}\Xi^*$	$|g_i|$ $\bar{K}^*\Xi$	$\bar{K}^*\Xi^*$	$\rho\Omega$
				$I = 1, J^P = 3/2^-$, 'SU(6)'		
2018	267	<u>2.19</u>	1.64	2.14	1.75	0.25
2258	101	<u>0.54</u>	<u>1.23</u>	<u>0.13</u>	3.19	2.33
2288	32	<u>0.33</u>	<u>0.17</u>	<u>0.93</u>	2.29	3.11
2146	359	<u>2.30</u>	2.47			'SU(3)'

Table 6. Same as Table 1 for the sector $I = 1$, $J^P = 5/2^-$.

M_R [MeV]	Γ_R	$\bar{K}^*\Xi^*$	$|g_i|$ $\rho\Omega$
		$I = 1, J^P = 5/2^-$, 'SU(6)'	
2324	0	1.79	3.09

Table 7. Experimentally known Ω^* resonances [7,8,9,10]. The branching ratios are relative.

Resonance $I(J)^P$	Mass [MeV]	Width	Decay modes	Branching ratios
$\Omega^*(2250)^-$ $0(?^?)$ ***	2252 ± 9	55 ± 18	$\Xi^-\pi^+K^-$ $\Xi^{*0}K^-$	1 0.7 ± 0.2
$\Omega^*(2380)^-$ $?(?^?)$ **	2384 ± 13	26 ± 23	$\Xi^-\pi^+K^-$ $\Xi^{*0}K^-$ $\Xi^-\bar{K}^{*0}$	1 < 0.4 0.5 ± 0.3
$\Omega^*(2470)^-$ $?(?^?)$ **	2474 ± 12	72 ± 33	$\Omega^-\pi^+\pi^-$	

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