The pseudoscalar meson and baryon octet interaction with strangeness $S = -2$ in the unitary coupled-channel approximation

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Abstract

The interaction of the pseudoscalar meson and the baryon octet with strangeness $S = -2$ and isospin $I = 1/2$ is investigated by solving the Bethe–Salpeter equation in the infinite and finite volume respectively. It is found that there is a resonance state generated dynamically, which owns a mass of about 1550 MeV and a large decay width of 120–200 MeV. This resonance state couples strongly to the $\pi\Xi$ channel. Therefore, it might not correspond to the $X(1620)$ particle announced by Belle collaboration. At the same time, this problem is studied in the finite volume, and an energy level at 1570 MeV is obtained, which is between the $\pi\Xi$ and $K\Lambda$ thresholds and independent of the cubic box size.

Keywords: Bethe–Salpeter equation, chiral unitary approach, amplitude

1. Introduction

The experimental data on double strange baryons $\Xi(1620)$ and $\Xi(1690)$ are scarce, and the spin-parity of them are not determined, so they are labeled with one star and three stars respectively in the review of Particle Data Group [1]. Recently, the $\Xi(1620)$ particle has been reported to be observed in the decay of $\Xi^+ \rightarrow \Xi^- \pi^+ \pi^+$ by Belle collaboration, and the mass and decay width are measured as

$$M = 1610.4 \pm 6.0\text{stat}^{+6.1}_{-4.2}\text{syst}\text{MeV},$$

$$\Gamma = 59.9 \pm 4.8\text{stat}^{+2.8}_{-2.7}\text{syst}\text{MeV},$$

respectively. Moreover, there is also some evidence of the $\Xi(1690)$ particle with the same data sample [2].

The masses of these two particles are about 300 MeV higher than that of the $\Xi$ hyperon, and thus they can be regarded as excited states of the $\Xi$ hyperon. However, they are difficult to be described within the framework of the constituent quark model.

In [3], the $\Xi(1620)$ particle is assumed to be a resonance state of the pseudoscalar meson and baryon octet with strangeness $S = -2$ and spin $J = 1/2$ in the unitary coupled-channel approximation of the Bethe–Salpeter equation. It shows that this resonance state couples strongly to the $\pi\Xi$ and $K\Lambda$ channels, and its width is sensitive to the subtraction constants related to these two channels. The properties of $\Xi(1620)$ are studied by solving the Bethe–Salpeter equation in [4]. Apparently, the method is the same as that used in [3], but with the kernel introduced by the vector meson exchange interaction. It manifests that the $\Xi(1620)$ particle might be a $K\Lambda$ or $K\Sigma$ bound state. Moreover, the decay width of $\Xi(1620) \rightarrow \Xi\pi$ is calculated, where $K\Lambda$ and $K\Sigma$ are treated as the intermediate state respectively, and the result indicates that the component of $K\Lambda$ is larger than $K\Sigma$ in the $\Xi(1620)$ particle. Consequently, the radiative decay process of $\Xi(1620)$ is analyzed systematically in [5] by assuming the $\Xi(1620)$ particle to be a $K\Lambda$ and $K\Sigma$ bound state with spin-parity $J^P = 1/2^-$.

In [6], a series of non-leptonic weak decays of $\Xi$ into $\pi\Xi$ and a meson–baryon final state are discussed, and the invariant mass distribution of the meson–baryon final state is analyzed within three different chiral schemes. However, it is found that the peak that appeared in the $\pi\Xi$ and $K\Lambda$ spectra is more possible to be $\Xi(1690)$, but not the $\Xi(1620)$ particle.

The unitary coupled-channel approximation of Bethe–Salpeter equation in the finite volume has made a great success in the study of the meson–meson interaction [7–12] and the meson–baryon interaction [13, 14]. Actually, a scheme to simulate the Lattice data in order to obtain the kernel of...
Bethe–Salpeter equation in the unitary coupled-channel approximation is proposed in these articles. Sequentially an attempt has been made to fit the lattice finite volume energy levels from $\pi\eta$ scattering and the properties of $d_0(980)$ is evaluated [15]. This method is also extended to study the interaction of the $\pi D_0, \eta D$ and $\bar K D_0$ channels in $J^P=0^+$ in the finite volume by fitting the lattice QCD calculation results [16], and along with this clue, more research works have been done by various groups worldwide.

In this work, the interaction between the pseudoscalar meson and baryon octet with strangeness $S=-2$ will be studied, and then the Bethe–Salpeter equation in the infinite and finite volume will be solved within the unitary coupled-channel approximation respectively. We will try to distinguish whether there are resonance states generated dynamically or not, and if so, whether the resonance state can be treated as a counterpart of the $\Xi'(1620)$ particle.

This article is organized as follows. In section 2, the potential of the pseudoscalar meson and baryon octet is constructed. In section 3, a basic formula on how to solve the Bethe–Salpeter equation in the unitary coupled-channel approximation is shown. Consequently, the pole position in the complex energy plane is obtained by solving the Bethe–Salpeter equation in the infinite volume, and its coupling constants to different channels are calculated. The chiral unitary approach in a finite box is introduced in section 4. Finally, the summary is given in section 5.

### 2. Interaction of the pseudoscalar meson and the baryon octet

The Weinberg–Tomozawa contact term of the pseudoscalar meson and the baryon octet takes the form of

$$V_{ij}^{\text{con}} = -C_0 \frac{1}{4\sqrt{s}} (2\sqrt{s} - M_i - M_j) \left( \frac{M_i + E}{2M_i} \right)^{\frac{1}{2}} \left( \frac{M_i + E'}{2M_j} \right)^{\frac{1}{2}},$$

where $\sqrt{s}$ is the total energy of the system, $M_i$ and $M_j$ denote the initial and final baryon masses, $E$ and $E'$ stand for the initial and final baryon energies in the center of mass frame, respectively. The coefficient $C_0$ for the sector of strangeness $S=-2$ and charge zero is listed in table 1. Moreover, we assume the decay constants are only relevant to the pseudoscalar meson with $f_0 = 1.34 f_\pi$, $f_K = 1.22 f_\pi$ and $f_\Sigma = 92.4$ MeV, as given in [17–21].

In the interaction of pseudoscalar meson and baryon octet, the contact potential originated from Weinberg–Tomozawa term plays a dominant role, and the correction from the $s$- and $u$-channel potentials can be neglected [21]. The Weinberg–Tomozawa term of the pseudoscalar meson and the baryon octet is only related to the Mandelstam variable $x$, therefore, it only gives a contribution to the S-wave amplitude in the scattering process of the pseudoscalar meson and the baryon octet.

**Table 1.** The coefficients $C_{ij}$ in the pseudoscalar meson and baryon octet interaction with strangeness $S=-2$ and charge $Q=0$, $C_{ij} = C_{ji}$.

| $C_{ij}$ | $\pi^0\Xi^-$ | $\pi^0\Xi^0$ | $\bar K^0\Lambda$ | $K^-\Sigma^+$ | $\bar K^0\Sigma^0$ | $\eta\Xi^0$ |
|----------|----------------|----------------|--------------------|----------------|--------------------|-----------|
| $\pi^0\Xi^-$ | 1 | $-\sqrt{2}$ | $\frac{3}{2}$ | 0 | $-\frac{1}{\sqrt{2}}$ | 0 |
| $\pi^0\Xi^0$ | 0 | $\sqrt{3}$ | $\frac{1}{2}$ | $-\frac{1}{\sqrt{2}}$ | 0 |
| $\bar K^0\Lambda$ | 0 | 0 | 0 | $-\frac{3}{2}$ |
| $K^-\Sigma^+$ | 1 | $-\sqrt{2}$ | $\frac{3}{2}$ |
| $\bar K^0\Sigma^0$ | 0 | $\sqrt{3}$ |
| $\eta\Xi^0$ | 0 |

In the sector of strangeness $S=-2$ and isospin $I = 1/2$, $C_{ji} = C_{ij}$.

| $C_{ij}$ | $\pi\Xi$ | $\bar K\Lambda$ | $\bar K\Sigma$ | $\eta\Xi$ |
|----------|----------|----------------|----------------|-----------|
| $\pi\Xi$ | 2 | $-\frac{3}{2}$ | $\frac{1}{2}$ | 0 |
| $\bar K\Lambda$ | 0 | 0 | $\frac{3}{2}$ |
| $\bar K\Sigma$ | 2 | $\frac{3}{2}$ |
| $\eta\Xi$ | 0 |

The wave function in the isospin space can be written as

$$\left| \pi\Xi; \frac{1}{2} \quad \frac{1}{2} \right> = \left( \frac{2}{\sqrt{3}} \right) |\pi^0\Xi^-> - \left( \frac{1}{\sqrt{3}} \right) |\pi^0\Xi^0>,$$

$$\left| \eta\Xi; \frac{1}{2} \quad \frac{1}{2} \right> = |\eta\Xi^0>,$$

$$\left| \bar K\Lambda; \frac{1}{2} \quad \frac{1}{2} \right> = |\bar K^0\Lambda>,$$

and

$$\left| \bar K\Sigma; \frac{1}{2} \quad \frac{1}{2} \right> = - \left( \frac{2}{\sqrt{3}} \right) |K^-\Sigma^+> + \left( \frac{1}{\sqrt{3}} \right) |\bar K^0\Sigma^0>,$$

respectively. Thus the coefficients $C_{ij}$ in the Weinberg–Tomozawa contact potential of the pseudoscalar meson and the baryon octet can be obtained in the isospin space, which are summarized in table 2.

In the case of isospin $I = 3/2$ and strangeness $S=-2$, the interaction of the pseudoscalar meson and the baryon octet is repulsive, therefore, no resonance states can be generated dynamically.

**Table 2.** The coefficients $C_{ij}$ in the pseudoscalar meson and baryon octet interaction with strangeness $S=-2$ and isospin $I = 1/2$, $C_{ji} = C_{ij}$.
3. Bethe–Salpeter equation

The scattering amplitude \( T(p_1, k_1; p_2, k_2) \) can be constructed by solving the Bethe–Salpeter equation

\[
T(p_1, k_1; p_2, k_2) = V(p_1, k_1; p_2, k_2) + \frac{i}{(2\pi)^3} \int \frac{d^4q}{\pi^2} V(p_1, k_1; q, P - q) S(q) \Delta(P - q) T(q, P - q; p_2, k_2),
\]

(7)

where \( P = p_1 + k_1 = p_2 + k_2 \) stands for the total momentum of the system, \( S(q) = \frac{\sigma^a q^a + \sigma^b q^b}{q^2 + M_b^2 + i\epsilon} \) and \( \Delta(P - q) = \frac{1}{(P - q)^2 - m_b^2 + i\epsilon} \) represent the baryon and meson propagators respectively.

The potential \( V(p, k; q, P - q) \) in equation (7) can be divided into an on-shell part and an off-shell part. At the meson–baryon threshold, the on-shell part of the potential is dominant and the off-shell part can be absorbed into the on-shell part of the potential if a suitable renormalization of coupling coefficients is performed. After that, the on-shell part of the potential can be taken out from the integral in equation (7) and the Bethe–Salpeter equation becomes an algebra equation when the on-shell approximation is taken into account, i.e.,

\[
T = V + VGT = (1 - VGT)^{-1}V,
\]

(8)

with the meson–baryon loop function

\[
G_i = \frac{i}{(2\pi)^3} \int \frac{d^4q}{\pi^2} \frac{\bar{q} + M_i}{q^2 - M_i^2 + i\epsilon} \frac{1}{(P - q)^2 - m_b^2 + i\epsilon}.
\]

(9)

The analytical form of the loop function \( G \) in equation (9) can be obtained in the dimensional regularization scheme. In [22], supposing \( \bar{q} + M_i = 2M_i \), a simplified form of the loop function in the dimensional regularization scheme is written as

\[
G_i^D(s) = \frac{2M_i}{16\pi^2} \left\{ a_i(\mu) + \ln \frac{m_i^2}{\mu^2} + \frac{M_i^2 - m_b^2 + s}{2s} \ln \frac{M_i^2}{m_b^2} + \frac{M_i^2 - m_b^2 - s}{2s} \ln \frac{M_i^2}{m_b^2} + \ln \frac{M_i^2}{m_b^2} \right\}
\]

\[
+ \frac{\bar{q}_i}{\sqrt{s}} \left\{ \ln(s - (M_i^2 - m_i^2) + 2\bar{q}_i\sqrt{s}) + \ln(s + (M_i^2 - m_i^2) + 2\bar{q}_i\sqrt{s}) - 0.3 \right\}
\]

\[
- \ln(-s - (M_i^2 - m_i^2) + 2\bar{q}_i\sqrt{s}) \right\},
\]

(10)

where \( \bar{q}_i \) stands for the three-momentum of the meson or the baryon in the center of mass frame, and \( \mu \) denotes the regularization scale and \( a_i(\mu) \) represents the subtraction constant. Although the regularization scale and the subtraction constant should be canceled by the higher-order contact terms in the perturbative theory, they are treated as fitting parameters in the unitary coupled-channel approximation. Apparently, these parameters reflect the influence of higher order terms not included in the potential when the Bethe–Salpeter equation is solved, just as iterated in [18, 19].

Actually, the on-shell condition \( \bar{q} + M_i = 2M_i \) is valid only when it acts on the real baryon. When the loop function \( G \) in equation (9) is calculated, the analytical form can be obtained directly without the on-shell condition taken into account, just as done in [20].

\begin{table}[h]
\centering
\caption{The subtraction constants \( a_j \) used in the calculation, where the regularization scale takes the value of 630 MeV, i.e. \( \mu = 630 \) MeV.}
\begin{tabular}{|c|c|c|c|c|}
\hline
\( a_{3\bar{q}} \) & \( a_{\bar{q}A} \) & \( a_{\bar{q}V} \) & \( a_{\bar{q}S} \) & \( a_{\bar{q}D} \) \\
\hline
Set 1 & -2.0 & -2.0 & -2.0 & -2.0 \\
Set 2 & -2.2 & -2.0 & -2.0 & -2.0 \\
Set 3 & -2.0 & -2.2 & -2.0 & -2.0 \\
Set 4 & -2.5 & -1.6 & -2.0 & -2.0 \\
Set 5 & -3.1 & -1.0 & -2.0 & -2.0 \\
\hline
\end{tabular}
\end{table}

\[
G_i^P = \frac{\sqrt{s}}{32\pi^2} \left\{ (a_i + 1)(m_i^2 - M_i^2) + \left( m_i^2 \ln \frac{m_i^2}{\mu^2} - M_i^2 \ln \frac{M_i^2}{\mu^2} \right) \right\}
\]

\[
+ \left( \frac{s + M_i^2 - m_b^2}{4M_i^2} \right) + \frac{1}{2} G_i^A,
\]

(11)

where some off-shell corrections have been taken into account. Although the on-shell condition \( ^*q^a + M_i = 2M_i \) is eliminated when the loop function is evaluated in the dimensional regularization scheme, the form of the Bethe–Salpeter equation in equation (8) should be solved in the present work, but not the formula in equation (7). Therefore, the whole calculation is carried out in an on-shell approximation.

In this work, these two kinds of loop functions will be adopted in the calculation, and the results will be compared to each other. As done in [20, 21], a transition of

\[
\tilde{V} = V\sqrt{\bar{M}\bar{M}_i}, \quad \tilde{G}_i = G_i/M_i
\]

is made when the Bethe–Salpeter equation is solved. Therefore, the scattering amplitude

\[
\tilde{T} = [1 - \tilde{V}\tilde{G}]^{-1}\tilde{V}
\]

(12)

becomes dimensionless.

The subtraction constants in the loop function of equations (10) and (11) are listed in table 3, which are cited from [3]. The regularization scale \( \mu \) is set to equal to the cutoff momentum of 630 MeV in order to obtain the same results as in [23], where the \( \bar{K}N \) interaction is investigated with a loop function in a momentum cut-off scheme by solving the Bethe–Salpeter equation. However, recently in the study of heavy mesons consisting of \( c \) or \( b \) quarks, the regularization scale is usually fixed to 1 GeV, just as done in [24]. Moreover, the relation of the regularization scale in the dimensional regularization scheme to the maximum momentum in the momentum cut-off scheme is discussed in detail in the \( B\bar{K} \) and \( B\bar{\pi} \) interaction [25].

With these subtraction constants and the regularization scale \( \mu = 630 \) MeV, the amplitudes of pseudoscalar meson and baryon octet are evaluated by solving the Bethe–Salpeter equation in the unitary coupled-channel approximation. A pole is detected around 1550 MeV in the complex energy plane and the pole position and coupling constants obtained with the loop functions in equations (10) and (11) are summarized in tables 4 and 5, respectively. Since the real part of
the pole position is higher than the $\pi \Xi$ threshold, and lower than the $K \Lambda$ threshold, it lies in the second Riemann sheet $S = -2$ and isospin $I = 1/2$. When the values of these subtraction constants change, the mass of this resonance state changes slightly, while the decay width of it changes in the range of 120–200 MeV. Apparently, both the mass and the decay width of this resonance state are far away from the experimental value supplied by Belle collaboration, and the results are also different from those in [3].

The coupling constants are calculated according to

$$\frac{g_0 g_s M_M}{\sqrt{s} - \sqrt{s_0}} = \tilde{T},$$

with $\sqrt{s_0}$ the pole position in the complex energy plane. This resonance state couples strongly to the $\pi \Xi$ channel, as listed in tables 4 and 5.

From tables 4 and 5, it is found that the real part of the pole position is about 100 MeV higher than the $\pi \Xi$ threshold and 50 MeV lower than the $K \Lambda$ threshold, hence it would mainly be a $\pi \Xi$ resonance state and couples strongly to the $\pi \Xi$ channel. However, the $\Xi(1620)$ particle announced by Belle collaboration almost locates at the $K \Lambda$ threshold in the range of uncertainty, hence it is more possible to be a molecule state of $K \Lambda$ and should couple strongly to the $K \Lambda$ channel. Therefore, the resonance state generated dynamically in the unitary coupled-channel approximation would not correspond to the $\Xi(1620)$ particle reported by Belle collaboration. In [3], in order to obtain a resonance mass close to the $\Xi(1620)$’s, the pion decay constant $f_\pi$ is enlarged, and an averaged value of $f = 1.123 f_\pi$ is adopted, just as done in their another work to discuss the antikaon-nucleon interaction [23].

Table 4. The pole position and corresponding coupling constants $g_i$ for different parameter sets calculated with the loop function in equation (10), where the pole position in the complex energy plane is in units of MeV.

| Pole position | Set 1       | Set 2       | Set 3       | Set 4       | Set 5       |
|--------------|-------------|-------------|-------------|-------------|-------------|
| $\pi \Xi$    | 1566-i119  | 1557-i99   | 1558-i113  | 1558-i83   | 1553-i60   |
| $\Sigma_0$   | 2.2-i1.5   | 2.2-i1.3   | 2.1-i1.5   | 2.2-i2.4   | 2.1-i0.8   |
| $\Sigma_0$   | -1.8+i0.6  | -1.8+i0.5  | -1.7+i0.6  | -1.9+i0.5  | -2.1+i0.4  |
| $\Sigma_0$   | -0.5+i0.3  | -0.5+i0.3  | -0.5+i0.3  | -0.6+i0.3  | -0.7+i0.2  |
| $\Sigma_0$   | 0.1-i0.3   | 0.1-i0.3   | 0.2-i0.3   | 0.0-i0.1   | -0.3-i0   |

Table 5. The pole position and corresponding coupling constants $g_i$ for different parameter sets calculated with the loop function in equation (11), where the pole position in the complex energy plane is in units of MeV.

| Pole position | Set 1       | Set 2       | Set 3       | Set 4       | Set 5       |
|--------------|-------------|-------------|-------------|-------------|-------------|
| $\pi \Xi$    | 1557-i104  | 1550-i89   | 1552-i100  | 1551-i78   | 1546-i60   |
| $\Sigma_0$   | 2.2-i1.4   | 2.2-i1.2   | 2.1-i1.4   | 2.2-i1.0   | 2.1-i1.0   |
| $\Sigma_0$   | -1.7+i0.5  | -1.7+i0.5  | -1.7+i0.5  | -1.8+i0.5  | -2.0+i0.4  |
| $\Sigma_0$   | -0.5+i0.3  | -0.5+i0.3  | -0.5+i0.3  | -0.6+i0.3  | -0.6+i0.2  |
| $\Sigma_0$   | 0.1-i0.3   | 0.1-i0.2   | 0.2-i0.3   | 0.0-i0.1   | -0.2-i0.0  |

4. The chiral unitary approach in a finite box

In order to obtain the energy level in a finite box, the loop function in equation (11) should be replaced by a $\tilde{G}$ when the Bethe–Salpeter equation is solved, where

$$\tilde{G}(E) = G^0(E) + \lim_{q_{\text{max}} \to \infty} \frac{1}{\mathcal{D}^2} \int_{q_{\text{max}}}^{q_{\text{max}}} d^4q \, I(q) - \int_{q_{\text{max}}}^{q_{\text{max}}} \frac{d^4q}{(2\pi)^4} \, I(q),$$

(14)
where

\[
I(q) = \frac{2M_I}{2\omega_I(q) \omega'_I(q)} \frac{\omega_I(q') + \omega'_I(q')}{E^2 - (\omega_I(q') + \omega'_I(q'))^2 + i\varepsilon}, \tag{15}
\]

considered. In figure 1, the real part of \( \tilde{G} - \tilde{G}^0 \) for the \( \bar{K}\Lambda \) channel is shown, which oscillates with \( q_{\text{max}} \) increasing. However, it converges when \( q_{\text{max}} \to +\infty \).

An analytical form on the integral in equation (14) can be found in the erratum of [26]. For the meson–baryon interaction, the integral in equation (14) is written as

\[
\int_{q < q_{\text{max}}} \frac{d^3q}{(2\pi)^3} I(q) = \frac{2M_I}{32\pi^2} \left( \frac{\Delta}{s} \log \frac{m_i^2}{M_i^2} + \frac{\nu}{s} \right) \left[ \log \frac{s - \Delta + \nu \sqrt{1 + M_i^2/q_{\text{max}}^2}}{-s - \Delta + \nu \sqrt{1 + M_i^2/q_{\text{max}}^2}} + \frac{2\Delta}{s} \log \frac{1}{1 + \sqrt{1 + M_i^2/q_{\text{max}}^2}} + 2 \log \left( 1 + \sqrt{1 + \frac{m_i^2}{q_{\text{max}}^2}} \right) \right], \tag{17}
\]

where \( \nu = \sqrt{[s - (m_i + M_i)^2][s - (m_i - M_i)^2]} \) and \( \Delta = M_i^2 - m_i^2 \). With the analytical form of the integral in equation (17), the real part of \( \tilde{G} - \tilde{G}^0 \) for the \( \bar{K}\Lambda \) channel is calculated again, and it almost repeats the result calculated with equation (14) directly, but without fluctuations, as depicted in figure 1.

The energy levels obtained in the box for different values of \( L \) are depicted in figure 2, and a smooth behavior of energy levels as a function of \( L \) is observed. In figure 2, the first 3 energy levels are almost invariant when the cubic box size \( L \) increases. Especially, the lowest and third levels are close to

Figure 1. Real part of the last two terms of the right hand side of equation (14) for the \( \bar{K}\Lambda \) channel. The solid line indicates the case with the analytical form in equation (17), while the dashed line represents oscillation results calculated with equation (14) directly.

Figure 2. Energy levels as functions of the cubic box size \( L \), derived from the chiral unitary approach in a box and using \( \tilde{G}(E) \) in equation (14).
the $\pi \Xi$ and $K \Lambda$ thresholds, respectively, therefore, they do not correspond to bound states of the pseudoscalar meson and baryon octet, but indicate the threshold effect in the finite volume. The second level lies at 1570 MeV, which is higher than the $\pi \Xi$ threshold, and can be regarded as a resonance state with strangeness $S = -2$ and isospin $I = 1/2$. Apparently, this energy level is far away from the mass of the $\Xi(1620)$ particle announced by Belle collaboration, and it would not be a counterpart of the $\Xi(1620)$ particle. At this point, it is consistent with the conclusion obtained in the infinite volume in section 3.

5. Summary

In this work, the interaction of the pseudoscalar meson and the baryon octet with strangeness $S = -2$ and isospin $I = 1/2$ is investigated by solving the Bethe–Salpeter equation in the unitary coupled-channel approximation. It is found that a resonance state is generated dynamically from the $\Xi(1620)$ particle announced by Belle collaboration. The coupled constants of this resonance state to different channels are calculated, and it couples strongly to the $\pi \Xi$ channel. Furthermore, this problem is also studied by solving the Bethe–Salpeter equation in the finite volume, and the energy levels at different cubic box sizes are obtained. It is found that the second energy level in the vicinity of 1570 MeV might be a resonance state of the pseudoscalar meson and baryon octet, while the first and third levels may come from the $\pi \Xi$ and $K \Lambda$ thresholds, respectively.

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References

[1] Zyla P A(Particle Data Group) et al 2020 Review of particle physics Prog. Theor. Exp. Phys. 2020 083C01 2021 update
[2] Sumihama M(Belle Collaboration) et al 2019 Observation of $\Xi(1620)^0$ and evidence for $\Xi(1690)^0$ in $\Xi + c \rightarrow \Xi - \pi + \pi^+$ decays Phys. Rev. Lett. 122 072501
[3] Ramos A, Oset E and Bennhold C 2002 On the spin, parity and nature of the $\Xi(1620)$ resonance Phys. Rev. Lett. 89 252001
[4] Wang Z Y, Qi J J, Xu J and Guo X H 2019 Analyzing $\Xi(1620)$ in the molecule picture in the Bethe–Salpeter equation approach Eur. Phys. J. C 79 640
[5] Huang Y, Yang F and Zhu H 2021 Radiative decay of the $\Xi(1620)$ in a hadronic molecule picture Chin. Phys. C 45 073112
[6] Miyahara K, Hyodo T, Oka M, Nieves J and Oset E 2017 Theoretical study of the $\Xi(1620)$ and $\Xi(1690)$ resonances in $\Xi c \rightarrow \pi + \pi MB$ decays Phys. Rev. C 95 035212
[7] Bernard V, Lage M, Meissner U G and Rusetsky A 2011 Scalar mesons in a finite volume J. High Energy Phys. JHEP01(2011)019
[8] Doring M, Meissner U G, Oset E and Rusetsky A 2011 Unitarized chiral perturbation theory in a finite volume: scalar meson sector Eur. Phys. J. A 47 139 Idem Eur. Phys. J. A 48, 114 (2012)
[9] Doring M, Haidenbauer J, Meissner U G and Rusetsky A 2011 Dynamical coupled-channel approaches on a momentum lattice Eur. Phys. J. A 47 163
[10] Martinez Torres A, Dai L R, Koren C, Jido D and Oset E 2012 The KD, $\Omega$D interaction in finite volume and the nature of the $D_{s0}(2317)$ resonance Phys. Rev. D 85 014027
[11] Albaredajo M, Oller J A, Oset E, Rios G and Roca L 2012 Finite volume treatment of $\pi \Xi$ scattering and limits to phase shifts extraction from lattice QCD J. High Energy Phys. JHEP08(2012)071
[12] Geng L S, Ren X L, Zhou Y, Chen H X and Oset E 2015 S-wave $K \Xi$ interactions in a finite volume and the f1(1285) Phys. Rev. D 92 014029
[13] Lage M, Meissner U G and Rusetsky A 2009 A method to measure the antikaon-nucleon scattering length in lattice QCD Phys. Lett. B 681 439
[14] Martinez Torres A, Bayar M, Jido D and Oset E 2012 Strategy to find the two/$\Lambda(1405)$ states from lattice QCD simulations Phys. Rev. C 86 055201
[15] Guo Z H, Liu L, Meissner U G, Oller J A and Rusetsky A 2017 Chiral study of the a0(980) resonance and $\pi \Xi$ scattering phase shifts in light of a recent lattice simulation Phys. Rev. D 95 054004
[16] Albaredajo M, Fernandez-Soler P, Guo F K and Niejes J 2017 Two-pole structure of the $D_{s0}(2400)$ Phys. Lett. B 767 465
[17] Inoue T, Oset E and Vicente Vacas M J 2002 Chiral unitary approach to S wave meson baryon scattering in the strangeness $S = 0$ sector Phys. Rev. C 65 035204
[18] Bruns P C, Mai M and Meissner U G 2011 Chiral dynamics of the S11(1535) and S11(1650) resonances revisited Phys. Lett. B 697 254
[19] Mai M and Meissner U G 2013 New insights into antikaon-nucleon scattering and the structure of the Lambda(1405) Nucl. Phys. A 900 51
[20] Dong F Y, Sun B X and Pang J L 2017 The $\Lambda(1405)$ state in a chiral unitary approach with off-shell corrections to dimensional regularized loop functions Chin. Phys. C 41 074108
[21] Sun B X, Zhao S Y and Wang X Y 2019 Pseudoscalar meson and baryon octet interaction with strangeness zero in the unitary coupled-channel approximation Chin. Phys. C 43 064111
[22] Oller J A and Meissner U G 2001 Chiral dynamics in the presence of bound states: Kaon nucleon interactions revisited Phys. Lett. B 500 263
[23] Oset E, Ramos A and Bennhold C 2002 Low lying $S = -1$ excited baryons and chiral symmetry Phys. Lett. B 527 99–105 [erratum: Phys. Lett. B 530, 260–260 (2002)]
[24] Fu H L, Griedhammer H W, Guo F K, Hanhart C and Meißner U G 2022 Update on strong and radiative decays of the $D_{s0}(2317)$ and $D_{s0}(2460)$ and their bottom cousins Eur. Phys. J. A 58 70
[25] Sun B X, Dong F Y and Pang J L 2017 Study of X(5568) in a unitary coupled-channel approximation of B$K$ and B$_s$ CHIN. PHYS. C 41 074104
[26] Oller J A, Oset E and Pelaez J R 1999 Meson meson interaction in a nonperturbative chiral approach Phys. Rev. D 59 074001 [Erratum-ibid. D 60, 099906 (1999)] [Erratum-ibid. D 75, 099903 (2007)]