Hexaquarks in the coupled-channel formalism

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Abstract

The relativistic six-quark equations are found in the framework of the dispersion relation technique. The approximate solutions of these equations using the method based on the extraction of leading singularities of the amplitudes are obtained. The relativistic six-quark amplitudes of hexaquarks including the quarks of three flavors \((u, d, s)\) are calculated. The poles of these amplitudes determine the masses of six-quark systems.

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I. Introduction.

In 1977, Jaffe [1] studied the color-magnetic interaction of the one-gluon-exchange potential in the multiquark system and found that the most attractive channel is the flavor singlet with quark content \(u^2d^2s^2\). The same symmetry analysis of the chiral boson exchange potential leads to the similar result [2].

However, the deuteron channel is not a channel with strong attraction in any baryon interaction model. If the deuteron had not been found experimentally, it seems highly unlikely that any model would have been able to predict it to be a stable dibaryon.

It is shown [3] that there are three types of baryon-baryon bound states. The states of the first type are called deuteron-like states. If chiral fields can provide enough attraction between interacting baryons, the systems would be weakly bound. The states of the second type such as \(\Delta\Delta\), \(\Sigma^*\Delta\) are named as \(\Delta\Delta\)-like states. Due to highly symmetric character in orbital space, these systems could be relatively deeply bound, but the strong decay modes of composed baryons cause the width of the states much broader.

The states of the third type are entitled as \(\Omega\Omega\)-like states. Due to the same symmetric character shown in the systems of the second type and the only weak decay mode of composed baryons, for instance \(\Omega\Omega\), these states are deeply bound states with narrow widths. The states of latter two types are most interesting new dibaryon states and should be carefully investigated both theoretically and experimentally [4 – 8].

There were number of theoretical predictions by using various models [3], the quark cluster model [10], the quark-delocation model [11, 12], the chiral \(SU(3)\) quark model [13], the flavor \(SU(3)\) skyrmion model [14]. Lomon predicted a deuteron-like dibaryon resonance using R-matrix theory [15]. By employing the chiral \(SU(3)\) quark model Zhang and Yu studied \(\Omega\Omega\) and \(\Sigma\Omega\) states [16, 17].

In the series of papers [18 – 22], a practical treatment of relativistic three-hadron systems has been developed. The physics of the three-hadron system is usefully described in terms of
the pairwise interactions among the three particles. The theory is based on the two principles of unitarity and analyticity, as applied to the two-body subenergy channels. The linear integral equations in a single variable are obtained for the isobar amplitudes. Instead of the quadrature methods of obtaining solution the set of suitable functions are identified and used as a basis for the expansion of the desired solutions. By this means the coupled integral equations are solved in terms of simple algebra. In the recent papers [23 – 25], the relativistic three-quark equations for the excited baryons are found in the framework of the dispersion relations technique. We have used the orbital-spin-flavor functions for the contribution of integral equations. We searched for the approximate solution of integral three-quark equations by taking into account two-particle and triangle singularities, all the weaker ones being neglected. If we considered such an approximation, which corresponds to taking into account two-body and triangle singularities, and defined all the smooth functions in the middle point the physical region of the Dalitz plot, then the problem was reduced to solving a system of simple algebraic equations. We calculated the mass spectra of excited baryons using the input four-fermion interaction with the quantum numbers of gluon [26].

In the present paper the relativistic six-quark equations are found in the framework of coupled-channel formalism. The dynamical mixing between the subamplitudes of hexaquark are considered. The six-quark amplitudes of hexaquarks are calculated. In Sec. II the relativistic six-quark equations are constructed in the form of the dispersion relation over the two-body subenergy. The approximate solutions of these equations using the method based on the extraction of leading singularities of the amplitude are obtained. Sec. III is devoted to the calculation results for the hexaquark mass spectra (Tables I and II). In the conclusion, the status of the considered model is discussed.

II. Six-quark amplitudes of the hexaquarks.

We derive the relativistic six-quark equations in the framework of the dispersion relation technique. We use only planar diagrams; the other diagrams due to the rules of $1/N_c$ expansion [27 – 29] are neglected. The current generates a six-quark system. The correct equations for the amplitude are obtained by taking into account all possible subamplitudes. It corresponds to the division of complete system into subsystems with a smaller number of particles. Then one should represent a six-particle amplitude as a sum of 15 subamplitudes:

$$A = \sum_{i<j}^{6} A_{ij} .$$ (1)

This defines the division of the diagrams into groups according to the certain pair interaction of particles. The total amplitude can be represented graphically as a sum of diagrams. We need to consider only one group of diagrams and the amplitude corresponding to them, for example $A_{12}$. We shall consider the derivation of the relativistic generalization of the Faddeev-Yakubovsky approach.

In our case the S-wave hexaquarks are considered. We take into account the pairwise interaction of all six quarks in the hexaquark.

For instance, we consider the $u^u$-diquarks with spin-parity $J^P = 1^+$ for the hexaquark content (uuuuuu) (Fig. 1). The set of diagrams associated with the amplitude $A_{12}$ can further be broken down into three groups corresponding to subamplitudes: $A_{1}^{u^u}(s, s_{12345}, s_{1234}, s_{123}, s_{12})$, $A_{2}^{u^u}(s, s_{12345}, s_{1234}, s_{12}, s_{34})$, $A_{3}^{u^u}(s, s_{12345}, s_{12}, s_{34}, s_{56})$. Here $s_{ik}$ is the two-particle subenergy squared, $s_{ijk}$ corresponds to the energy squared of particles $i, j, k$, $s_{ijkl}$ is the energy squared of particles $i, j, k, l$, $s_{ijklm}$ corresponds to the energy squared of particles $i, j, k, l, m$ and $s$ is the system total energy squared.

The system of graphical equations is determined by the subamplitudes using the self-consistent
The coefficients are determined by the permutation of quarks [30, 31]. In order to represent the subamplitudes $A_l$, $l = 1 - 3$ in the form of a dispersion relation, it is necessary to define the amplitudes of quark-quark interaction. The pair quarks amplitudes $qq \rightarrow qq$ are calculated in the framework of the dispersion $N/D$ method with the input four-fermion interaction [32 - 34] with the quantum numbers of the gluon [26, 35]. The regularization of the dispersion integral for the $D$-function is carried out with the cutoff parameter $\Lambda$.

The four-quark interaction is considered as an input:

$$
g_V \left( \bar{q} \lambda I_f \gamma^\mu q \right)^2 + 2 g_V^{(s)} \left( \bar{q} \lambda I_f \gamma^\mu q \right) \left( \bar{s} \lambda \gamma^\mu s \right) + g_V^{(ss)} \left( \bar{s} \lambda \gamma^\mu s \right)^2. \tag{2}
$$

Here $I_f$ is the unity matrix in the flavor space $(u, d)$, $\lambda$ are the color Gell-Mann matrices. Dimensional constants of the four-fermion interaction $g_V$, $g_V^{(s)}$, and $g_V^{(ss)}$ are parameters of the model.

At $g_V = g_V^{(s)} = g_V^{(ss)}$ the flavor $SU(3)_f$ symmetry occurs. The strange quark violates the flavor $SU(3)_f$ symmetry. In order to avoid additional violation parameters we introduce the scale of the dimensional parameters [35]:

$$
g = \frac{m^2}{\pi^2}g_V = \frac{(m + m_s)^2}{4\pi^2}g_V^{(s)} = \frac{m_s^2}{\pi^2}g_V^{(ss)}. \tag{3}
$$

Here $m_i$ and $m_k$ are the quark masses in the intermediate state of the quark loop. Dimensionless parameters $g$ and $\Lambda$ are supposed to be constants which are independent of the quark interaction type. The applicability of Eq. (2) is verified by the success of De Rujula-Georgi-Glashow quark model [26], where only the short-range part of Breit potential connected with the gluon exchange is responsible for the mass splitting in hadron multiplets. We use the results of our relativistic quark model [35] and write down the pair quark amplitudes in the form:

$$
a_n(s_{ik}) = \frac{G_n^2(s_{ik})}{1 - B_n(s_{ik})}, \tag{5}
$$

$$
B_n(s_{ik}) = \int \frac{ds_{ik}' \rho_n(s_{ik}') G_n^2(s_{ik}')} \pi \cdot s_{ik}' - s_{ik}. \tag{6}
$$

Here $G_n(s_{ik})$ are the diquark vertex functions (Table III). The vertex functions are determined by the contribution of the crossing channels. The vertex functions satisfy the Fierz relations. All of these vertex functions are generated from $g_V$, $g_V^{(s)}$ and $g_V^{(ss)}$. $B_n(s_{ik})$ and $\rho_n(s_{ik})$ are the Chew-Mandelstam functions with cutoff $\Lambda$ [36] and the phase spaces, respectively:

$$
\rho_n(s_{ik}, J^{PC}) = \left( \alpha(n, J^{PC}) \frac{s_{ik}}{(m_i + m_k)^2} + \beta(n, J^{PC}) + \delta(n, J^{PC}) \frac{(m_i - m_k)^2}{s_{ik}} \right)
\times \sqrt{(s_{ik} - (m_i + m_k)^2)(s_{ik} - (m_i - m_k)^2)} / s_{ik}. \tag{7}
$$

The coefficients $\alpha(n, J^{PC})$, $\beta(n, J^{PC})$ and $\delta(n, J^{PC})$ are given in Table III.

Here $n = 1$ corresponds to $qq$-pairs with $J^P = 0^+$, $n = 2$ corresponds to $qq$-pairs with $J^P = 1^+$. In the case in question the interacting quarks do not produce a bound state, therefore the integration in Eqs. (8) - (10) is carried out from the threshold $(m_i + m_k)^2$ to the cutoff $\Lambda(i\kappa)$. 


We consider the hexaquark state with the strangeness $S = 0$, the isospin $I = 3$ (spin-parity $J^P = 0^+, 2^+$).

Fig. 1. Graphic representation of the equations for the six-quark subamplitudes $A_l$ ($l = 1, 2, 3$) in the case of the spin-parity $J^P = 0^+, 2^+$ (quark content $(uuuuuu)$).
The coupled integral equations correspond to Fig. 1 can be described as:

\[
A_1^{1uu}(s, s_{12345}, s_{1234}, s_{123}, s_{12}) = \frac{\lambda_1 B_{1uu}(s_{12})}{[1 - B_{1uu}(s_{12})]} + 8\hat{J}_1(s_{12}, 1^{uu})A_1^{1uu}(s, s_{12345}, s_{1234}, s_{123}, s_{13}') \\
+ 12\hat{J}_2(s_{12}, 1^{uu})A_2^{1uu1uu}(s, s_{12345}, s_{1234}, s_{13}', s_{24}') ,
\]

(8)

\[
A_2^{1uu1uu}(s, s_{12345}, s_{1234}, s_{12}, s_{34}) = \frac{\lambda_2 B_{1uu}(s_{12})B_{1uu}(s_{34})}{[1 - B_{1uu}(s_{12})][1 - B_{1uu}(s_{34})]} \\
+ 4\hat{J}_3(s_{12}, s_{34}, 1^{uu}, 1^{uu})A_1^{1uu}(s, s_{12345}, s_{1234}, s_{123}', s_{23}') \\
+ 8\hat{J}_4(s_{12}, s_{34}, 1^{uu}, 1^{uu})A_1^{1uu}(s, s_{12345}, s_{1235}, s_{125}, s_{15}') \\
+ 4\hat{J}_5(s_{12}, s_{34}, 1^{uu}, 1^{uu})A_2^{1uu1uu}(s, s_{12356}, s_{1256}, s_{15}', s_{26}') \\
+ 8\hat{J}_6(s_{12}, s_{34}, 1^{uu}, 1^{uu})A_2^{1uu1uu}(s, s_{12456}, s_{1456}, s_{15}', s_{46}') \\
+ 16\hat{J}_7(s_{12}, s_{34}, 1^{uu}, 1^{uu})A_2^{1uu1uu}(s, s_{12345}, s_{2345}, s_{23}', s_{45}') \\
+ 8\hat{J}_8(s_{12}, s_{34}, 1^{uu}, 1^{uu})A_3^{1uu1uu1uu}(s, s_{12345}, s_{15}', s_{23}', s_{46}') ,
\]

(9)

\[
A_3^{1uu1uu1uu}(s, s_{12345}, s_{12}, s_{34}, s_{56}) = \frac{\lambda_3 B_{1uu}(s_{12})B_{1uu}(s_{34})B_{1uu}(s_{56})}{[1 - B_{1uu}(s_{12})][1 - B_{1uu}(s_{34})][1 - B_{1uu}(s_{56})]} \\
+ 12\hat{J}_9(s_{12}, s_{34}, s_{56}, 1^{uu}, 1^{uu}, 1^{uu})A_1^{1uu}(s, s_{12345}, s_{1234}, s_{13}', s_{23}') \\
+ 24\hat{J}_{10}(s_{12}, s_{34}, s_{56}, 1^{uu}, 1^{uu}, 1^{uu})A_2^{1uu1uu}(s, s_{12345}, s_{2345}, s_{23}', s_{45}') ,
\]

(10)

where

\[
\hat{J}_1(s_{12}, i) = \frac{G_i(s_{12})}{[1 - B_i(s_{12})]} \int_0^{(m_1 + m_2)^2} ds'_{12} G_i(s'_{12})\rho_i(s'_{12}) \int_{-1}^{+1} dz_1(1) \int_{-1}^{+1} dz_2(2) \\
+ \int_{z_3(2)}^{z_3(2)^+} dz_3(2) \frac{1}{\sqrt{1 - z_1^2(2) - z_2^2(2) - z_3^2(2) + 2z_1(2)z_2(2)z_3(2)}} ,
\]

(11)

\[
\hat{J}_2(s_{12}, i) = \frac{G_i(s_{12})}{[1 - B_i(s_{12})]} \int_0^{(m_1 + m_2)^2} ds'_{12} G_i(s'_{12})\rho_i(s'_{12}) \int_{-1}^{+1} dz_1(2) \int_{-1}^{+1} dz_2(2) \\
\times \int_{z_3(2)}^{z_3(2)^+} dz_3(2) \frac{1}{\sqrt{1 - z_1^2(2) - z_2^2(2) - z_3^2(2) + 2z_1(2)z_2(2)z_3(2)}} ,
\]

(12)
\[\dot{J}_3(s_{12}, s_{34}, i, j) = \frac{G_i(s_{12})G_j(s_{34})}{[1 - B_i(s_{12})][1 - B_j(s_{34})]} \int \frac{ds'_{12} G_i(s'_{12}) \rho_i(s'_{12})}{\pi} \frac{(m_1 + m_2)^2 \Lambda_j}{s'_{12} - s_{12}} \]
\[\times \int \frac{ds'_{34} G_j(s'_{34}) \rho_j(s'_{34})}{\pi} \frac{1}{s'_{34} - s_{34}} \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{1}(3) \right] \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{2}(3) \right] \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{3}(3) \right] ,\]
(13)

\[\dot{J}_4(s_{12}, s_{34}, i, j) = \frac{B_j(s_{34})}{[1 - B_j(s_{34})]} \dot{J}_1(s_{12}, i) ,\]
(14)

\[\dot{J}_5(s_{12}, s_{34}, i, j) = \frac{B_j(s_{34})}{[1 - B_j(s_{34})]} \dot{J}_2(s_{12}, i) ,\]
(15)

\[\dot{J}_6(s_{12}, s_{34}, i, j) = \dot{J}_1(s_{12}, i) \cdot \dot{J}_1(s_{34}, j) ,\]
(16)

\[\dot{J}_7(s_{12}, s_{34}, i, j) = \frac{G_i(s_{12})G_j(s_{34})}{[1 - B_i(s_{12})][1 - B_j(s_{34})]} \int \frac{ds'_{12} G_i(s'_{12}) \rho_i(s'_{12})}{\pi} \frac{(m_1 + m_2)^2 \Lambda_j}{s'_{12} - s_{12}} \]
\[\times \int \frac{ds'_{34} G_j(s'_{34}) \rho_j(s'_{34})}{\pi} \frac{1}{s'_{34} - s_{34}} \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{1}(7) \right] \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{2}(7) \right] \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{3}(7) \right] \]
\[\times \int \frac{dz_{4}(7)}{z_{4}(7)^+} \frac{1}{\sqrt{1 - z_{1}^{2}(7) - z_{3}^{2}(7) - z_{4}^{2}(7) + 2z_{1}(7)z_{3}(7)z_{4}(7)}} ,\]
(17)

\[\dot{J}_8(s_{12}, s_{34}, i, j) = \frac{G_i(s_{12})G_j(s_{34})}{[1 - B_i(s_{12})][1 - B_j(s_{34})]} \int \frac{ds'_{12} G_i(s'_{12}) \rho_i(s'_{12})}{\pi} \frac{(m_1 + m_2)^2 \Lambda_j}{s'_{12} - s_{12}} \]
\[\times \int \frac{ds'_{34} G_j(s'_{34}) \rho_j(s'_{34})}{\pi} \frac{1}{s'_{34} - s_{34}} \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{1}(8) \right] \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{2}(8) \right] \left[ \frac{1}{2} \int_{-1}^{1} d\zeta_{3}(8) \right] \]
\[\times \int \frac{dz_{4}(8)}{z_{4}(8)^+} \frac{1}{\sqrt{1 - z_{1}^{2}(8) - z_{3}^{2}(8) - z_{4}^{2}(8) + 2z_{1}(8)z_{3}(8)z_{4}(8)}} \times \frac{1}{\sqrt{1 - z_{2}^{2}(8) - z_{3}^{2}(8) - z_{4}^{2}(8) + 2z_{2}(8)z_{5}(8)z_{6}(8)}} ,\]
(18)

\[\dot{J}_9(s_{12}, s_{34}, s_{56}, i, j, k) = \frac{B_k(s_{56})}{[1 - B_k(s_{56})]} \dot{J}_3(s_{12}, s_{34}, i, j) ,\]
(19)
\[ \hat{J}_{10}(s_{12}, s_{34}, s_{56}, i, j, k) = \frac{G_i(s_{12})G_j(s_{34})G_k(s_{56})}{[1 - B_i(s_{12})][1 - B_j(s_{34})][1 - B_k(s_{56})]} \int \frac{ds'_{12}}{(m_1 + m_2)^2 \Lambda_k} \frac{ds'_{34}}{(m_3 + m_4)^2 \Lambda_j} \frac{ds'_{56}}{(m_5 + m_6)^2 \Lambda_k} \times \frac{1}{\pi} \frac{1}{s'_{12} - s_{12}} \]

\[ \times \left( \frac{G_i(s'_{12})\rho_i(s'_{12})}{s'_{12}} \right)^{(m_1 + m_2)^2 \Lambda_k} \times \left( \frac{G_j(s'_{34})\rho_j(s'_{34})}{s'_{34} - s_{34}} \right)^{(m_3 + m_4)^2 \Lambda_j} \times \left( \frac{G_k(s'_{56})\rho_k(s'_{56})}{s'_{56} - s_{56}} \right)^{(m_5 + m_6)^2 \Lambda_k} \]

\[ \times \left( \int \frac{dz_1(10)}{2\pi z_1(10)} + \int \frac{dz_2(10)}{2\pi z_2(10)} + \int \frac{dz_3(10)}{2\pi z_3(10)} + \int \frac{dz_4(10)}{2\pi z_4(10)} + \int \frac{dz_5(10)}{2\pi z_5(10)} \right) \]

\[ \times \sqrt{1 - z_1^2(10) - z_2^2(10) - z_3^2(10) + 2z_1(10)z_2(10)z_3(10)z_4(10)z_5(10)}. \]  

We should discuss the coefficients multiplying of the diagrams in the equations of Fig. 1. For example, we consider the first subamplitude \( A_1(s, s_{12345}, s_{1234}, s_{123}, s_{12}) \). In the Eq. (8) (Fig. 1) the first coefficient is equal to 8, that the number \( 8 = 2 \) (permutation particles 1 and 2) \( \times 4 \) (we can use third, 4-th, 5-th, 6-th particles); the second coefficient equal to 12 that the number \( 12 = 4 \) (used third, 4-th, 5-th, 6-th particles) \( \times 3 \) (in this case we can consider 4-th, 5-th, 6-th particles). The similar approach allows us to take into account the coefficients in the Eqs. (9) and (10).

Let us extract two- and three-particle singularities in the amplitudes \( A_1^{1uu}(s, s_{12345}, s_{1234}, s_{123}, s_{12}) \), \( A_2^{1uu1uu}(s, s_{12345}, s_{1234}, s_{12}, s_{34}) \), \( A_3^{1uu1uu1uu}(s, s_{12345}, s_{12}, s_{34}, s_{56}) \):

\[ A_1^{1uu}(s, s_{12345}, s_{1234}, s_{123}, s_{12}) = \frac{\alpha_1^{1uu}(s, s_{12345}, s_{1234}, s_{123}, s_{12})B_1^{1uu}(s_{12})}{[1 - B_1^{1uu}(s_{12})]}. \]  

\[ A_2^{1uu1uu}(s, s_{12345}, s_{1234}, s_{12}, s_{34}) = \frac{\alpha_2^{1uu1uu}(s, s_{12345}, s_{1234}, s_{12}, s_{34})B_1^{1uu}(s_{12})B_1^{1uu}(s_{34})}{[1 - B_1^{1uu}(s_{12})][1 - B_1^{1uu}(s_{34})]}. \]  

\[ A_3^{1uu1uu1uu}(s, s_{12345}, s_{12}, s_{34}, s_{56}) = \frac{\alpha_3^{1uu1uu1uu}(s, s_{12345}, s_{12}, s_{34}, s_{56})B_1^{1uu}(s_{12})B_1^{1uu}(s_{34})B_1^{1uu}(s_{56})}{[1 - B_1^{1uu}(s_{12})][1 - B_1^{1uu}(s_{34})][1 - B_1^{1uu}(s_{56})]}. \]  

We do not extract four-particles singularities, because they are weaker than two- and three-particle singularities.

We used the classification of singularities, which was proposed in paper [37]. The construction of the approximate solution of Eqs. (21) – (23) is based on the extraction of the leading singularities of the amplitudes. The main singularities in \( s_{ik} = (m_i + m_k)^2 \) are from pair rescattering of the particles \( i \) and \( k \). First of all there are threshold square-root singularities. Also possible are pole singularities which correspond to the bound states. The diagrams of Fig. 1 apart two-particle singularities have triangular singularities and the singularities defining the interactions of four, five and six particles. Such classification allows us to search the corresponding solution of Eqs. (8) – (10) by taking into account some definite number of leading singularities and neglecting all the weaker ones. We consider the approximation which defines two-particle, triangle and four-, five- and six-particle singularities. The contribution of two-particle and triangle singularities are more important, but we must take into account also the other singularities.

The functions \( \alpha_l, l = 1 - 3 \) are the smooth functions of \( s_{ik}, s_{ij}, s_{ijkl} \) as compared with the singular part of the amplitudes, hence they can be expanded in a series should be employed
further. Using this classification, one defines the reduced amplitudes \( \alpha_1, \alpha_2, \alpha_3 \) as well as the \( B \)-functions in the middle point of physical region of Dalitz-plot at the point \( s_0 \):

\[
s_0 = s + 4 \sum_{i=1}^{6} m_i^2, \quad \sum_{i<k}^{6} m_{ik}^2
\]

(24)

\[
s_{123} = s_0 \sum_{i,k=1}^{3} m_{ik}^2 - \sum_{i=1}^{3} m_i^2,
\]

(25)

\[
s_{1234} = s_0 \sum_{i,k=1}^{4} m_{ik}^2 - \sum_{i=1}^{4} m_i^2.
\]

(26)

Such choice of point \( s_0 \) allows us to replace integral equations (8) – (10) (Fig. 1) by the algebraic equations (27) – (29), respectively:

\[
\alpha_1^{1u} = \lambda + 8I_1(1^{uu}1^{uu})\alpha_1^{1u} + 12I_2(1^{uu}1^{uu})\alpha_2^{1u1u},
\]

(27)

\[
\alpha_2^{1u1u} = \lambda + 4I_3(1^{uu}1^{uu})\alpha_1^{1u} + 8I_4(1^{uu}1^{uu})\alpha_1^{1u} + 4I_5(1^{uu}1^{uu})\alpha_2^{1u1u} + 8I_6(1^{uu}1^{uu})\alpha_2^{1u1u} + 16I_7(1^{uu}1^{uu})\alpha_2^{1u1u} + 8I_8(1^{uu}1^{uu})\alpha_3^{1u1u1u},
\]

(28)

\[
\alpha_3^{1u1u1u} = \lambda + 12I_9(1^{uu}1^{uu})\alpha_1^{1u} + 24I_{10}(1^{uu}1^{uu})\alpha_2^{1u1u},
\]

(29)

where \( \lambda \) is the current constants. We used the functions \( I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8, I_9, I_{10} \):

\[
I_1(ij) = \frac{B_j(s_{13}^{13})}{B_i(s_{02}^{12})} \left( \frac{(m_1+m_2)^2}{(m_1+m_2)^2} \right)^{\Lambda_i} \int_{-1}^{1} dz_1(1) \frac{1}{2} \frac{1}{1-B_j(s_{13}^{12})},
\]

(30)

\[
I_2(ijk) = \frac{B_j(s_0^{13})B_k(s_0^{24})}{B_i(s_0^{12})} \left( \frac{(m_1+m_2)^2}{(m_1+m_2)^2} \right)^{\Lambda_i} \int_{-1}^{1} dz_1(1) \frac{1}{2} \frac{1}{1-B_j(s_{13}^{12})} \frac{1}{2} \frac{1}{1-B_k(s_{24}^{24})},
\]

(31)
\[
I_4(ijk) = I_1(ik),
\]
\[
I_5(ijkl) = I_2(ikl),
\]
\[
I_6(ijkl) = I_1(ik) \cdot I_1(jl),
\]
\[
I_7(ijkl) = \frac{B_k(s_0^{23}) B_l(s_0^{45})}{B_l(s_0^{12}) B_j(s_0^{34})} \frac{(m_1 + m_2)^2 \Lambda_i}{(m_1 + m_2)^2} \int \frac{ds_{12}'}{\pi} \frac{G^2(s_0^{34}) \rho_j(s_{34}')}{s_{34}' - s_0^{34}} \int \frac{dz_1(7)}{2} \int \frac{dz_2(7)}{2} \int \frac{dz_3(7)}{2} \frac{1}{1 - B_k(s_{23}')}.
\]
\[
I_8(ijklm) = \frac{B_k(s_0^{15}) B_l(s_0^{23}) B_m(s_0^{46})}{B_l(s_0^{12}) B_j(s_0^{34})} \frac{(m_1 + m_2)^2 \Lambda_i}{(m_1 + m_2)^2} \int \frac{ds_{12}'}{\pi} \frac{G^2(s_0^{12}) \rho_i(s_{12}')}{s_{12}' - s_0^{12}} \int \frac{dz_1(8)}{2} \int \frac{dz_2(8)}{2} \int \frac{dz_3(8)}{2} \int \frac{dz_4(8)}{2} \int \frac{dz_5(8)}{2} \int \frac{dz_6(8)}{2} \frac{1}{1 - B_k(s_{23}') - B_l(s_{45}') - B_m(s_{46}')},
\]
\[
I_9(ijkl) = I_3(ijl),
\]
\[ I_{10}(ijklm) = \frac{B_l(s'_{23}^3)B_m(s'_{45}^3)}{B_1(s_0^{12})B_2(s_0^{34})B_3(s_0^{56})} \int_0^{(m_1+m_2)^2/\Lambda} ds'_{12} \frac{G_i^2(s_0^{12} \rho_i(s'_{12}))}{s'_{12} - s_0^{12}} \]
\[ \times \int_0^{(m_3+m_4)^2/\Lambda} ds'_{34} \frac{G_j^2(s_0^{34} \rho_j(s'_{34}))}{s'_{34} - s_0^{34}} \int_0^{(m_5+m_6)^2/\Lambda} ds'_{56} \frac{G_k^2(s_0^{56} \rho_k(s'_{56}))}{s'_{56} - s_0^{56}} \]
\[ = \frac{1}{2\pi} \int_{-1}^{+1} dz_1(10) \frac{1}{2} \int_{-1}^{+1} dz_2(10) \frac{1}{2} \int_{-1}^{+1} dz_3(10) \frac{1}{2} \int_{-1}^{+1} dz_4(10) \]
\[ \times \int_{-1}^{+1} dz_5(10) \frac{1}{\sqrt{1 - z_1^2(10) - z_2^2(10) - z_3^2(10) + 2z_1(10)z_4(10)z_5(10)}} \]
\[ \times \frac{1}{1 - B_l(s'_{23}) - B_m(s'_{45})}, \quad (39) \]

where \( i, j, k, l, m \) correspond to the quarks with the spin-parity \( J^P = 0^+, 1^+ \).

In the equation (30) \( z_1(1) \) is the cosine of the angle between the relative momentum of particles 1 and 2 in the intermediate state and the momentum of the particle 3 in the final state taken in the c.m. of particles 1 and 2. We can go from the integration of the cosine of the angle \( dz_1(1) \) to the integration over the subenergy \( ds'_{13} \).

In Eq. (31) \( z_2(2) \) is the cosine of the angle between the relative momentum of particles 1 and 2 in the intermediate state and the momentum of the particle 3 in the final state taken in the c.m. of particles 1 and 2, \( z_2(2) \) is the cosine of the angle between the momenta of particles 3 and 4 in the final state of c.m. of particles 1 and 2, \( z_3(2) \) is cosine of the angle between the relative momentum of particles 1 and 2 in the intermediate state and the momentum of the particle 4 in the final state of c.m. of particles 1 and 2. Then we pass from \( dz_1(2)dz_2(2)dz_3(2) \) to \( ds'_{13}ds'_{34}ds'_{24} \).

In Eq. (32) \( z_1(3) \) is the cosine of the angle between the relative momentum of particles 1, 2 in the intermediate state and the relative momentum of particles 3, 4 in the intermediate state in c.m. of particles 3 and 4; \( z_3(3) \) is the cosine of the angle between momentum of particle 3 in the intermediate state and relative momentum of particles 1, 2 in the intermediate state in c.m. 1 and 2. We pass from \( dz_1(3)dz_2(3) \) to \( ds'_{123}ds'_{23} \). The similar method are used for the functions (33) - (35), (38).

In Eq. (36) \( z_1(7) \) is cosine of the angle between relative momentum of the particles 1, 2 in the intermediate state and the relative momentum of particles 3, 4 in the intermediate state in c.m. of particles 3 and 4; \( z_2(7) \) is the cosine of the angle between the momentum of particle 3 in the intermediate state and relative momentum of particles 1, 2 in the intermediate state in c.m. of particles 1 and 2; \( z_3(7) \) is cosine of the angle between momentum of particle 5 in the final state and relative momentum of particles 1, 2 in the intermediate state in c.m. of particles 3 and 4; \( z_4(7) \) is cosine of the angle between momentum of particle 5 in the final state and the relative momentum of particles 3, 4 in the intermediate state in c.m. of particles 3 and 4. Then we translated the \( dz_1(7)dz_2(7)dz_3(7)dz_4(7) \) to \( ds'_{123}ds'_{23}ds'_{125}ds'_{45} \).

In Eq. (37) \( z_1(8) \) is the cosine of the angle between momentum of particle 5 in the final state and the relative momentum of particles 1, 2 in the intermediate state in c.m. of particles 1 and 2; \( z_2(8) \) is the cosine of the angle between the relative momentum of particles 1, 2 in the intermediate state and the relative momentum of particles 3, 4 in the intermediate state in c.m. of particles 3 and 4; \( z_3(8) \) is the cosine of the angle between momentum of particle 3 in the intermediate state and the momentum of particle 5 in the final state in c.m. of particles 1.
and 2; \( z_4(8) \) is the cosine of the angle between the momentum of particle 3 in the intermediate state and the relative momentum of particles 1, 2 in the intermediate state in c.m. of particles 1 and 2; \( z_5(8) \) is the cosine of angle between momentum of particle 6 in the final state and the relative momentum of particles 1, 2 in the intermediate state in c.m. of particles 3 and 4; \( z_6(8) \) is the cosine of the angle between momentum of particle 6 in the final state and the relative momentum of particles 3, 4 in the intermediate state in c.m. of particles 3 and 4. We pass from \( dz_1(8)dz_2(8)dz_3(8)dz_4(8)dz_5(8)dz_6(8) \) to \( ds'_{15}ds'_{123}ds'_{35}ds'_{235}ds_{126}ds_{46} \).

In Eq. (39) \( z_1(10) \) is the cosine of angle between relative momentum of particles 1, 2 in the intermediate state and the relative momentum of particles 3, 4 in the intermediate state in c.m. of particles 3 and 4; \( z_2(10) \) is the cosine of angle between the relative momentum of particles 1, 2 in the intermediate state and momentum of particle 3 in the final state in c.m. of particles 1 and 2; \( z_3(10) \) is the cosine of the angle between the relative momentum of the particles 3, 4 in the intermediate state and the relative momentum of particles 5, 6 in the intermediate state in c.m. of particles 5 and 6; \( z_4(10) \) is the cosine of angle between relative momentum of particles 1, 2 in the intermediate state and the momentum of particle 5 in the final state in c.m. of particles 3 and 4; \( z_5(10) \) is the cosine of the angle between the relative momentum of the particles 3, 4 in the intermediate state and the momentum of particle 5 in the final state in c.m. of particles 3 and 4. We pass from \( dz_1(10)dz_2(10)dz_3(10)dz_4(10)dz_5(10) \) to \( ds'_{123}ds'_{23}ds'_{345}ds'_{126}ds'_{45} \).

The other choices of point \( s_0 \) do not change essentially the contributions of \( \alpha_i, l = 1 - 3 \), therefore we omit the indices \( s_i^k \). Since the vertex functions depend only slightly on energy, it is possible to treat them as constants in our approximation.

The solutions of the system of equations are considered as:

\[
\alpha_i(s) = F_i(s, \lambda_i)/D(s),
\]

where zeros of \( D(s) \) determinants define the masses of bound states of dibaryons.

As example, we consider the equations for the quark content \( uuuuuu \) with the strangeness \( S = 0 \), the isospin \( I = 3 \) and the spin-parity \( J^P = 0^+, 2^+ \) (Fig. 1). The similar equations have been calculated for the strangeness \( S = 0, -1, -2, -3, -4, -5, -6 \), the isospin \( I = 0, \frac{1}{2}, 1, \frac{3}{2}, 2, \frac{5}{2}, 3 \) and the spin-parity \( J^P = 0^+, 1^+, 2^+ \). We take into account the \( u, d, s \) quarks.

In Appendix I the \( NN_{SIJ=001}, \Delta\Delta_{SIJ=001}, \Omega\Omega_{SIJ=-600}, \Lambda\Lambda_{SIJ=-200}, N\Omega_{SIJ=-3\frac{1}{2}} \) dibaryons are given.

**III. Calculation results.**

The poles of the reduced amplitudes \( \alpha_i \) \( (i = 1 - 3) \) correspond to the bound state and determine the mass of the hexaquark with the quark content \( (uuuuuu) \), with the isospin \( I = 3 \) and the spin-parity \( J^P = 0^+, 2^+ \). The quark masses of model \( m_{u,d} = 410 \, MeV \) and \( m_s = 557 \, MeV \) coincide with the ordinary baryon ones in our model [38].

The model in question has only three parameters: the cutoff parameter \( \Lambda = 11 \) (similar to the model [41]) and the gluon coupling constants \( g_0 \) and \( g_1 \). These parameters are determined by the \( \Lambda\Lambda \) and the \( \text{di-}\Omega \) masses. We have considered the two type of calculations. In the first case we use the gluon coupling constants \( g_1 = 0.292 \) (diquark \( 1^+ \)) and \( g_0 = 0.653 \) (diquark \( 0^+ \)). Which are fitted by the \( \Lambda\Lambda \) state with the \( M = 2173 \, MeV \) and the \( \text{di-}\Omega \) with the \( M = 3232 \, MeV \), respectively. In the second case the gluon coupling constants \( g_1 = 0.325 \) and \( g_0 = 0.647 \) are determined by the masses of \( \Lambda\Lambda \) state with the \( M = 2171 \, MeV \) and the \( \text{di-}\Omega \) state \( M = 3093 \, MeV \). The experimental data of these masses are absent, therefore we use the paper [12]. In our model the correlation of gluon coupling constants \( g_0 \) and \( g_1 \) is similar to the S-wave baryon ones [38].

The estimation of theoretical error on the S-wave hexaquarks masses is 1 MeV. This results was obtained by the choice of model parameters. We predict the deuteron state as the mix of S- and D-wave contributions. \( NN_{SIJ=001} \) with the mass \( M = 1865 \, MeV \) and \( \Delta\Delta_{SIJ=001} \) with the
mass $M = 1834\, MeV$). The experimental value of deuteron mass is $M = 1876\, MeV$. In the cases of the $NN$, $\Delta\Delta$, $N\Delta$ systems the Pauli principle requires that $(-1)^{L+I+J} = (-1)$, where $L$ the orbital moment, $I$ isospin, $J$ spin of state are respectively. The wave function of dibaryon must be antisymmetric for the permutation of all quarks. If we consider the generalized Pauli rule for the wave function of dihyperons, we must add the strangeness contribution to the isospin $I + \frac{S}{2}$. Then we obtain the formula $(-1)^{L+I+\frac{S}{2}+J} = (-1)$. This rule allows us to suggest the classification of dibaryons with the certain strangeness, isospin and spin-parity (Tables I and II). We predict the degeneracy of the some states. The contributions of subamplitudes to the hexaquark amplitude are shown in the Appendix I (for example, $\Lambda\Lambda_{SIJ=−200}$). The nonstrange dibaryon with the isospin $I = 1$ and the spin-parity $J^P = 0^+$ is absent.

The states $N\Delta$ and $\Delta\Delta$ with the isospin $I = 1$ and the spin-parity $J^P = 2^+$ possess the mass $M = 2020\, MeV$. For the $N\Delta$ and $\Delta\Delta$ with the isospin $I = 2$ and the spin-parity $J^P = 1^+$ we obtained the mass $M = 1984\, MeV$. For the state $\Delta\Delta$ with the isospin $I = 3$ and the spin-parity $J^P = 0^+$, $2^+$ ($M = 2379\, MeV$) the degeneracy is predicted. It is shown in the Table I.

The results for the strange sector of model are given in Table I and II.

IV. Conclusion.

The dibaryon physics can be very delicate [39 – 41]. The deuteron channel is not a channel with strong attraction in any baryon interaction model. If the deuteron had not been found experimentally, it seems highly unlikely that any model would have been able to predict it to be a stable dibaryon.

The H-particle ($SIJ = −200$) is a six quark state consisting mainly of octet-baryons, similar to the deuteron and one can find only a weak attraction in the model [41]. Hence, a qualitative analysis is insufficient to judge whether or not the H-particle is strong interaction stable. Systematically, the authors find that a strong attraction develops only in decuplet-decuplet channels and a mild attraction in octet-decuplet channels [41]. Moreover, in the H-particle case, the channel coupling effect may even be more important than the deuteron case. In fact, it is bound without taking coupled channels into account. Besides the binding energy of the H, an interesting question regarding the H is its compactness, i.e. whether the H is a compact 6-quark object or a loosely bound $\Lambda\Lambda$ state.

For systems with strangeness $S = −3$, Pang et al. have calculated the state $N\Omega(SIJ = −3\frac{1}{2}2)$, which was shown to be midly attractive, with energy below $\Lambda\Xi\pi$ threshold.

They have carried out a dynamical channel coupling calculation to examine this state further. The $N\Omega$, $\Lambda\Xi^*$, $\Xi\Sigma^*$, $\Sigma\Xi^*$ $\Xi^*\Sigma^*$ channels are all included. The authors find this to be a compact six quark state [41].

For systems with $S = −4$, with the quantum numbers $SIJ = −410$ as an example, the lowest mass channel is composed of two octet baryons from the same isodublet. The result shows that the system with $S = −4$, $I = 1$, $J = 0$ is unbound, even when the $\Xi^*\Xi^*$ and $\Sigma^*\Omega$ channel couplings are taken into account.

For comparison, Pang et al. have also calculated the $SIJ = −401$ state. The $\Xi\Xi$, $\Xi\Xi^*$, $\Lambda\Omega$ and $\Xi^*\Xi^*$ coupling channels are included. The result is very similar to the $SIJ = −410$, i.e. they do not find a bound state in this channel.

For the systems with $S = −5$, Pang et al. take the $SIJ = −5\frac{1}{2}0$ state as an example. This state is interesting as a Pauli principle favored state. If only two-baryon S-wave channels are taken into account, there is only one channel for this state. The calculation shows [41] that the contribution of the kinetic energy term, due to quark exchange and delocalization effects, contributes strongly towards the formation of a bound state. However, the one-gluon-exchange interaction largely compensates for this attraction. Pang et al. conclude that this state is not a good candidate for a dibaryon resonance search due to its small binding.
In the paper [41], Pang et al. would present a systematic study of possible candidates of S-wave baryon-baryon bound states.

The H-particle, $N\Omega$-state and di-$\Omega$ may be strong interaction stable. Up to now, these three interesting candidates of dibaryons are still not found or confirmed by experiments. It seems that one should go beyond these candidates and should search the possible candidates in a wider region, especially the systems with multi-strangeness, in terms of a more reliable model.

In our model the deuteron consist of the $\Delta\Delta$, $NN$ contributions (the strangeness $S = 0$, the isospin $I = 0$, spin-parity $J^P = 1^+$, the quark content is $uuuddd$). The H-particle ($SIJ = -200$) content includes $N\Xi$, $\Sigma\Sigma^*$, $\Xi\Sigma^*$, $\Lambda\Lambda$.

For the systems with strangeness $S = -3$ ($N\Omega$ $SIJ = -3\frac{1}{2}2$) the $N\Omega$, $\Lambda\Xi^*$, $\Xi\Sigma^*$, $\Sigma \Sigma^*$, $\Xi^*\Sigma^*$ channels are included.

For the di-$\Omega$ state we consider the strangeness $S = -6$ ($SIJ = -600$).

The gluon coupling constants in our model is determined by the masses of the H-particle and di-$\Omega$ state (Table I and II).

We considered 39 dibaryons, calculated the masses these states with the strangeness $S = 0, -1, -2, -3, -4, -5, -6$ and the spin-parity $J^P = 0^+, 1^+, 2^+$.

In our paper the dynamics of quark interactions in defined by the Gbew-Mandelstam functions (Table III). We include only three parameters: the cutoff $\Lambda$, gluon coupling constants $g_0, g_1$. The relativistic six-body approach gives rise to the dynamical mixing of the six-quark amplitudes and the dibaryon amplitudes. We calculated the masses of two groups of dibaryons (Table I and II), which similar to the results of other papers [12, 38 – 40]. In our paper the relativistic description of six particles amplitudes of S-wave dibaryons are considered. We use only three parameters for the calculations of 39 dibaryon masses. The interesting research is the consideration of the $qqqqqQ$ states with $Q$ a heavy quark ($Q = c, b$).

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Appendix I. The reduced amplitudes of dibaryons $NN_{SIJ=001}$; $\Delta \Delta_{SIJ=001}$, $\Omega_{SIJ=−600}$, \Lambdabar_{SIJ=−200}, $N\Omega_{SIJ=−3\frac{1}{2}}$.

$NN_{SIJ=001}$:

\[
\begin{align*}
\alpha_{11}^{uu} &= \lambda + 2\alpha_1^{1u}I_1(1^{uu}1^{uu}) + 6\alpha_1^{0ud}I_1(1^{uu}0^{ud}) + 6\alpha_2^{1us0ud}I_2(1^{uu}1^{uu}0^{ud}) + 6\alpha_2^{0ud0ud}I_2(1^{uu}0^{ud}0^{ud})
\end{align*}
\]

\[
\begin{align*}
\alpha_{11}^{dd} &= \lambda + 2\alpha_1^{1dd}I_1(1^{dd}1^{dd}) + 6\alpha_1^{0dd}I_1(1^{dd}0^{dd}) + 6\alpha_2^{1dd0dd}I_2(1^{dd}1^{dd}0^{dd}) + 6\alpha_2^{0dd0dd}I_2(1^{dd}0^{dd}0^{dd})
\end{align*}
\]

\[
\begin{align*}
\alpha_{11}^{0ud} &= \lambda + 2\alpha_1^{1uu}I_1(0^{ud}1^{uu}) + 2\alpha_1^{1dd}I_1(0^{ud}1^{dd}) + 4\alpha_1^{0ud}I_1(0^{ud}0^{ud}) + 4\alpha_2^{1uu1dd}I_2(0^{ud}1^{uu}1^{dd})
\end{align*}
\]

\[
\begin{align*}
\alpha_{11}^{1uu1dd} &= \lambda + \alpha_1^{0ud}(4I_3(1^{uu}1^{dd}0^{ud}) + 2I_4(1^{uu}1^{dd}0^{ud}) + 2I_4(1^{dd}1^{uu}0^{ud})) + 2\alpha_2^{1uu0ud}I_5(1^{uu}1^{dd}1^{uu}0^{ud})
\end{align*}
\]

\[
\begin{align*}
\alpha_{11}^{1uu0ud} &= \lambda + 2\alpha_1^{1uu}I_3(1^{uu}0^{ud}1^{uu}) + 2\alpha_1^{1dd}I_4(0^{ud}1^{uu}1^{dd}) + \alpha_1^{0ud}(2I_3(1^{uu}0^{ud}0^{ud}) + 4I_4(1^{uu}0^{ud}0^{ud})
\end{align*}
\]

\[
\begin{align*}
\alpha_{11}^{1dd0ud} &= \lambda + \alpha_1^{0ud}(4I_3(1^{uu}1^{dd}0^{ud}) + 2I_4(1^{uu}1^{dd}0^{ud}) + 2I_4(1^{dd}1^{uu}0^{ud})) + 2\alpha_2^{1uu0ud}I_5(1^{uu}1^{dd}1^{uu}0^{ud})
\end{align*}
\]

\[
\begin{align*}
\alpha_{11}^{1dd0ud} &= \lambda + \alpha_1^{0ud}(4I_3(1^{uu}1^{dd}0^{ud}) + 2I_4(1^{uu}1^{dd}0^{ud}) + 2I_4(1^{dd}1^{uu}0^{ud})) + 2\alpha_2^{1uu0ud}I_5(1^{uu}1^{dd}1^{uu}0^{ud})
\end{align*}
\]

\[
\begin{align*}
\alpha_{11}^{0ud0ud} &= \lambda + 2\alpha_1^{1uu}(I_3(1^{uu}0^{ud}1^{uu}) + 2I_4(0^{ud}0^{ud}1^{uu})) + \alpha_1^{1dd}(I_3(1^{uu}0^{ud}1^{dd}) + 2I_4(0^{ud}0^{ud}1^{dd}))
\end{align*}
\]
\[
\alpha_1^{0ud} = 2 I_3(0^{ud}0^{ud}0^{ud}) + 4 I_4(0^{ud}0^{ud}0^{ud}) + \alpha_2^{1uu1dd}(2 I_5(0^{ud}0^{ud}1^{uu}1^{dd}) + 2 I_6(0^{ud}0^{ud}1^{uu}1^{dd})
\]
\[
= 2 I_7(0^{ud}0^{ud}1^{dd}1^{uu}) + 2 I_7(0^{ud}0^{ud}1^{uu}1^{dd}) + \alpha_2^{1uu0ud}(2 I_6(0^{ud}0^{ud}1^{uu}0^{ud}) + 2 I_7(0^{ud}0^{ud}1^{uu}0^{ud})
\]
\[
= 2 I_7(0^{ud}0^{ud}0^{ud}1^{uu}) + \alpha_2^{1dd0ud}(2 I_6(0^{ud}0^{ud}0^{ud}1^{dd}) + 2 I_7(0^{ud}0^{ud}0^{ud}1^{dd}) + 2 I_7(0^{ud}0^{ud}1^{dd}0^{ud})
\]
\[
+ \alpha_2^{0ud0ud}(2 I_5(0^{ud}0^{ud}0^{ud}0^{ud}) + 2 I_6(0^{ud}0^{ud}0^{ud}0^{ud}) + 4 I_7(0^{ud}0^{ud}0^{ud}0^{ud})
\]
\[
+ \alpha_3^{1uu1dd0ud}(2 I_8(0^{ud}0^{ud}1^{uu}0^{ud}1^{dd}) + 2 I_8(0^{ud}0^{ud}1^{uu}1^{dd}0^{ud}) + 2 I_8(0^{ud}0^{ud}0^{ud}1^{uu}1^{dd})
\]

\[
\alpha_3^{1uu1dd0ud} = \lambda + 2 \alpha_1^{1uu} I_9(1^{uu}0^{ud}1^{dd}1^{uu}) + 2 \alpha_1^{1dd} I_9(1^{dd}0^{ud}1^{uu}1^{dd}) + \alpha_1^{0ud}(4 I_9(1^{uu}1^{dd}0^{ud}0^{ud})
\]
\[
+ 2 I_9(1^{uu}0^{ud}1^{dd}0^{ud}) + 2 I_9(1^{dd}0^{ud}10^{ud}) + 4 \alpha_2^{1uu1dd} I_{10}(1^{uu}0^{ud}1^{dd}1^{uu}1^{dd})
\]
\[
+ 4 \alpha_2^{1uu0ud} I_{10}(1^{dd}1^{uu}0^{ud}0^{ud}1^{uu}) + 4 \alpha_2^{1dd0ud} I_{10}(1^{uu}1^{dd}0^{ud}0^{ud}1^{dd})
\]
\[
+ \alpha_2^{0ud0ud}(4 I_{10}(1^{uu}1^{dd}0^{ud}0^{ud}0^{ud}) + 4 I_{10}(1^{dd}1^{uu}0^{ud}0^{ud}0^{ud}) + 4 I_{10}(1^{uu}0^{ud}1^{dd}0^{ud}0^{ud})
\]

\[
\Delta \Delta S_{IJ=001}:
\]
\[
\alpha_1^{1uu} = \lambda + 2 \alpha_1^{1uu} I_1(1^{uu}1^{uu}) + 6 \alpha_1^{0ud} I_1(1^{uu}0^{ud}) + 6 \alpha_2^{1uu0ud} I_2(1^{uu}1^{uu}0^{ud}) + 6 \alpha_2^{0ud0ud} I_2(1^{uu}0^{ud}0^{ud})
\]
\[
\alpha_1^{1dd} = \lambda + 2 \alpha_1^{1dd} I_1(1^{dd}1^{dd}) + 6 \alpha_1^{0ud} I_1(1^{dd}0^{ud}) + 6 \alpha_2^{1dd0ud} I_2(1^{dd}1^{dd}0^{ud}) + 6 \alpha_2^{0ud0ud} I_2(1^{dd}0^{ud}0^{ud})
\]
\[
\alpha_1^{0ud} = \lambda + 2 \alpha_1^{1uu} I_1(0^{ud}1^{uu}) + 2 \alpha_1^{1dd} I_1(0^{ud}1^{dd}) + 4 \alpha_1^{0ud} I_1(0^{ud}0^{ud}) + 4 \alpha_2^{1uu1dd} I_2(0^{ud}1^{uu}1^{dd})
\]
\[
+ 2 \alpha_2^{1uu0ud} I_2(0^{ud}1^{uu}0^{ud}) + 2 \alpha_2^{1dd0ud} I_2(0^{ud}0^{ud}1^{dd}) + 4 \alpha_2^{0ud0ud} I_2(0^{ud}0^{ud}0^{ud})
\]
\[
\alpha_2^{1uu1dd} = \lambda + 2 \alpha_1^{1uu} I_4(1^{uu}1^{dd}1^{uu}) + 2 \alpha_1^{1dd} I_4(1^{dd}1^{uu}1^{dd}) + \alpha_1^{0ud}(4 I_5(1^{uu}1^{dd}0^{ud}) + 2 I_4(1^{uu}1^{dd}0^{ud})
\]
\[
+ 2 I_4(1^{dd}1^{uu}0^{ud}) + 4 \alpha_2^{1uu1dd} I_6(1^{uu}1^{dd}1^{uu}1^{dd}) + \alpha_2^{1uu0ud}(2 I_5(1^{uu}1^{dd}1^{uu}0^{ud})
\]
\[
+ 4 I_7(1^{dd}1^{uu}0^{ud}1^{uu}) + \alpha_2^{1dd0ud}(2 I_5(1^{dd}1^{uu}0^{ud}1^{dd}) + 4 I_7(1^{uu}1^{dd}0^{ud}1^{dd})
\]
\[
+ \alpha_2^{0ud0ud}(4 I_6(1^{uu}1^{dd}0^{ud}0^{ud}) + 4 I_7(1^{uu}1^{dd}0^{ud}0^{ud}) + 4 I_7(1^{dd}1^{uu}0^{ud}0^{ud})
\]
\[
+ 4 \alpha_3^{1uu1dd0ud} I_8(1^{uu}1^{dd}1^{uu}0^{ud}1^{dd})
\]
\[
\alpha_2^{1uu0ud} = \lambda + 2 \alpha_1^{1uu} I_3(1^{uu}0^{ud}1^{uu}) + 2 \alpha_1^{1dd} I_4(0^{ud}1^{uu}1^{dd}) + \alpha_1^{0ud}(2 I_3(1^{uu}0^{ud}0^{ud}) + 4 I_4(1^{uu}0^{ud}0^{ud})
\]
\[
\begin{align*}
\alpha_2^{1dd0ud} &= \lambda + 2 \alpha_1^{1uu} I_4(0ud1uu0ud) + 2 \alpha_1^{1dd} I_3(1dd0ud1dd) + \alpha_1^{0ud} (2 I_5(1dd0ud0ud) + 2 I_4(1dd0ud0ud)) \\
&+ 2 I_4(0ud1dd0ud)) + 4 \alpha_2^{1uu1dd} I_7(1uu0ud1uu1dd) + \alpha_2^{0ud} (2 I_5(0ud1dd0ud1uu) + 2 I_5(0ud1dd0ud0ud)) \\
&+ 2 I_7(0ud0ud1uu1dd) + 2 I_7(0uu0ud1uu1dd)) + \alpha_2^{0ud} (2 I_6(0uu0ud1uu0ud) + 2 I_7(0uu0ud1uu0ud)) \\
&+ 2 I_7(0gg0ud0ud1uu) + \alpha_2^{gg0ud} (2 I_6(0gg0ud0ud1dd) + 2 I_7(0gg0ud0ud1dd) + 2 I_7(0gg0ud1dd0ud)) \\
&+ \alpha_2^{gg0ud} (2 I_5(0gg0ud0ud0ud) + 2 I_6(0gg0ud0ud0ud) + 4 I_7(0gg0ud0ud0ud)) \\
&+ \alpha_3^{1uu1dd0ud} (2 I_8(0uu0ud1uu0ud1dd) + 2 I_8(0uu0ud1uu0ud1dd) + 2 I_7(0uu0ud1uu0ud1dd)) \\
&= \lambda + 2 \alpha_1^{1uu} I_9(1uu0ud1dd1uu) + 2 \alpha_1^{1dd} I_9(1dd0ud1uu1dd) + \lambda_1^{0ud} (4 I_9(1uu1dd0ud0ud) \\
&+ 2 I_9(1uu0ud1dd0ud) + 2 I_9(1dd0ud1uu0ud)) + 4 \alpha_2^{1uu0ud} I_{10}(1dd0ud1uu1dd) \\
&+ 4 \alpha_2^{1uu0ud} I_{10}(1dd0ud0ud1uu) + 4 I_2^{1dd0ud} I_{10}(1uu1dd0ud0ud1dd) \\
&+ \alpha_2^{0ud} (4 I_{10}(1uu1dd0ud0ud0ud) + 4 I_{10}(1dd1uu0ud0ud0ud) + 4 I_{10}(1uu0ud1dd0ud0ud))}
\end{align*}
\]
\[\Omega_{SIJ=-600}:\]

\[
\alpha_{1}^{ss} = \lambda + 8 \alpha_{1}^{ss} I_{1}(1^{ss}1^{ss}) + 12 \alpha_{2}^{1ss1ss} I_{2}(1^{ss}1^{ss})
\]

\[
\alpha_{2}^{1ss1ss} = \lambda + \alpha_{1}^{ss} (4 I_{6}(1^{ss}1^{ss}1^{ss})) + 8 I_{4}(1^{ss}1^{ss}1^{ss}) + \alpha_{2}^{1ss1ss} (4 I_{5}(1^{ss}1^{ss}1^{ss})) + 8 I_{6}(1^{ss}1^{ss}1^{ss}1^{ss}) + 16 I_{7}(1^{ss}1^{ss}1^{ss}1^{ss}) + 8 \alpha_{3}^{1ss1ss1ss} I_{8}(1^{ss}1^{ss}1^{ss}1^{ss})
\]

\[
\alpha_{3}^{1ss1ss1ss} = \lambda + 12 \alpha_{1}^{ss} I_{9}(1^{ss}1^{ss}1^{ss}1^{ss}) + 24 \alpha_{2}^{1ss1ss} I_{10}(1^{ss}1^{ss}1^{ss}1^{ss})
\]

\[\Lambda_{SIJ=-200}:\]

\[
\alpha_{1}^{1uu} = \lambda + 4 \alpha_{1}^{0ud} I_{1}(1^{uu}0^{ud}) + 4 \alpha_{1}^{0us} I_{1}(1^{uu}0^{us}) + 2 \alpha_{2}^{0ud0ud} I_{2}(1^{uu}0^{ud}) + 8 \alpha_{2}^{0ud0us} I_{2}(1^{uu}0^{us})
\]

\[
\alpha_{1}^{1dd} = \lambda + 4 \alpha_{1}^{0ud} I_{1}(1^{dd}0^{ud}) + 4 \alpha_{1}^{0ds} I_{1}(1^{dd}0^{ds}) + 2 \alpha_{2}^{0ud0ud} I_{2}(1^{dd}0^{ud}) + 8 \alpha_{2}^{0ud0ds} I_{2}(1^{dd}0^{ds})
\]

\[
\alpha_{1}^{1ss} = \lambda + 4 \alpha_{1}^{0us} I_{1}(1^{ss}0^{us}) + 4 \alpha_{1}^{0ds} I_{1}(1^{ss}0^{ds}) + 2 \alpha_{2}^{0us0us} I_{2}(1^{ss}0^{us}) + 8 \alpha_{2}^{0us0ds} I_{2}(1^{ss}0^{ds})
\]

\[
\alpha_{1}^{0ud} = \lambda + \alpha_{1}^{1uu} I_{1}(0^{ud}1^{uu}) + \alpha_{1}^{1dd} I_{1}(0^{ud}1^{dd}) + 2 \alpha_{1}^{0ud} I_{1}(0^{ud}0^{ud}) + 2 \alpha_{1}^{0us} I_{1}(0^{ud}0^{us})
\]

\[
\alpha_{1}^{0us} = \lambda + \alpha_{1}^{1uu} I_{1}(0^{us}1^{uu}) + \alpha_{1}^{1ss} I_{1}(0^{us}1^{ss}) + 2 \alpha_{1}^{0ud} I_{1}(0^{us}0^{ud}) + 2 \alpha_{1}^{0us} I_{1}(0^{us}0^{us})
\]

\[
\alpha_{1}^{0ds} = \lambda + \alpha_{1}^{1dd} I_{1}(0^{ds}1^{dd}) + \alpha_{1}^{1ss} I_{1}(0^{ds}1^{ss}) + 2 \alpha_{1}^{0ud} I_{1}(0^{ds}0^{ud}) + 2 \alpha_{1}^{0ds} I_{1}(0^{ds}0^{ds})
\[
\alpha_2^{0u0dus} = \lambda + \alpha_1^{us} I_3(0u0d0u0us) + \alpha_1^{dd} I_3(0u0d0u0ud) + 2 \alpha_1^{0ud} I_3(0u0d0u0ud) + 4 \alpha_1^{0us} I_4(0u0d0u0us)
\]

\[
= 4 \alpha_1^{0us} I_4(0u0d0u0ds) + 4 \alpha_2^{0u0dus} I_7(0u0d0u0ud0us) + 4 \alpha_2^{0u0dus} I_7(0u0d0u0ud0ds) + 2 \alpha_2^{0u0dus} I_6(0u0d0u0us0us) + 4 \alpha_2^{0u0dus} I_5(0u0d0u0us0us) + I_6(0u0d0u0us0us)
\]

\[
= 2 \alpha_2^{0d0us} I_6(0u0d0u0us0ds) + 4 \alpha_3^{0d0us} I_8(0u0d0u0us0us0us)
\]
\[
\begin{align*}
\alpha_{010}^{0\alpha} &= \lambda + \alpha_{11}^{0\alpha} I_3(0us00ds1\alpha s) + \alpha_{11}^{0\alpha} (I_3(0us00ds0ud) + I_4(0us00ds0ud) + I_4(00ds0us0ud)) \\
&+ \alpha_{010}^{0\alpha} (I_3(0us00ds0ud) + I_4(00ds0us00ud)) + \alpha_{010}^{0\alpha} (I_3(0us00ds0\alpha d) + I_4(00ds0us0\alpha d)) \\
&+ \alpha_{20000}^{0\alpha} - I_6(00us00ds0\alpha d) + \alpha_{20000}^{0\alpha} (I_5(00ds00ud0us) + I_6(00us00ds00ud) + I_7(0us00ds00ud)) \\
&+ I_7(0us00ds00ud0\alpha d) + \alpha_{20000}^{0\alpha} (I_5(00ds00us00ud) + I_6(00us00ds00ud) + I_7(0us00ds00ud)) \\
&+ I_7(00ds00ds00ud0\alpha d) + \alpha_{20000}^{0\alpha} (I_6(00ds00ds00us) + I_7(00ds00ds00us) + I_7(00ds00ds00us)) \\
&+ \alpha_{30000}^{0\alpha} (I_8(0us00ds00ud00us) + I_8(0us00ds00ds00us) + I_8(0us00ds00ds00ud)) \\
\end{align*}
\]

\[
\begin{align*}
\alpha_{20000}^{0\alpha} &= \lambda + \alpha_{11}^{0\alpha} I_3(00ds00ds1\alpha d) + \alpha_{11}^{0\alpha} I_3(00ds00ds1\alpha d) + 4 \alpha_{010}^{0\alpha} I_4(00ds00ds00ud) + 4 \alpha_{010}^{0\alpha} I_4(00ds00ds00us) \\
&+ 2 \alpha_{010}^{0\alpha} - I_3(00ds00ds00ds) + 2 \alpha_{010}^{0\alpha} - I_7(00ds00ds00ud00ud) + 4 \alpha_{20000}^{0\alpha} (I_5(00ds00ds00ud0us) \\
&+ I_6(00ds00ds00us00ud)) + 4 \alpha_{010}^{0\alpha} (I_7(00ds00ds00us00us) + I_7(00ds00ds00us00us)) \\
&+ 4 \alpha_{20000}^{0\alpha} I_7(00ds00ds00ds00us) + 2 \alpha_{30000}^{0\alpha} I_8(00ds00ds00ds00us) \\
\end{align*}
\]

\[
\begin{align*}
\alpha_{30000}^{0\alpha} &= \lambda + \alpha_{11}^{0\alpha} I_3(00\alpha d00ds00ds1\alpha d) + \alpha_{11}^{0\alpha} I_3(00\alpha d00ds00ds1\alpha d) + 4 \alpha_{11}^{0\alpha} I_9(00\alpha d00ds00ds1\alpha d) + 4 \alpha_{11}^{0\alpha} I_9(00\alpha d00ds00ds1\alpha d) \\
&+ \alpha_{11}^{0\alpha} (I_9(00\alpha d00ds00ds00us) + I_9(00\alpha d00ds00ds00us)) + 4 \alpha_{010}^{0\alpha} (I_9(00\alpha d00ds00ds00us) + I_9(00\alpha d00ds00ds00us)) \\
&+ I_9(00\alpha d00ds00us00us) + I_9(00\alpha d00ds00us00us) + \alpha_{11}^{0\alpha} (I_9(00\alpha d00ds00us00us) + I_9(00\alpha d00ds00us00us)) \\
&+ I_9(00\alpha d00ds00ds00us) + I_9(00\alpha d00ds00ds00us) + \alpha_{11}^{0\alpha} (I_9(00\alpha d00ds00ds00us) + I_9(00\alpha d00ds00ds00us)) \\
&+ I_9(00\alpha d00ds00ds00ds) + \alpha_{20000}^{0\alpha} I_10(00\alpha d00ds00ds00ds00us) + \alpha_{20000}^{0\alpha} (I_10(00\alpha d00ds00ds00ds00us) \\
&+ I_10(00\alpha d00ds00ds00ds00us) + I_10(00\alpha d00ds00ds00ds00us)) + \alpha_{20000}^{0\alpha} (I_10(00\alpha d00ds00ds00ds00us) + I_10(00\alpha d00ds00ds00ds00us)) \\
&+ \alpha_{20000}^{0\alpha} (I_10(00\alpha d00ds00ds00ds00ds) + I_10(00\alpha d00ds00ds00ds00ds)) + \alpha_{20000}^{0\alpha} (I_10(00\alpha d00ds00ds00ds00ds) + I_10(00\alpha d00ds00ds00ds00ds)) \\
&+ \alpha_{20000}^{0\alpha} (I_10(00\alpha d00ds00ds00ds00ds) + I_10(00\alpha d00ds00ds00ds00ds)) + \alpha_{20000}^{0\alpha} (I_10(00\alpha d00ds00ds00ds00ds) + I_10(00\alpha d00ds00ds00ds00ds)) \\
&+ \alpha_{20000}^{0\alpha} I_10(00\alpha d00ds00ds00ds00ds) \\
\end{align*}
\]
\[ N \Omega_{S,I,J} = \frac{-3}{2} \]

\[
\begin{align*}
\alpha_1^{1uu} &= \lambda + 2 \alpha_1^{0ud} I_1(1uu0ud) + 6 \alpha_1^{0us} I_1(1uu0us) \\
\alpha_1^{1ss} &= \lambda + 2 \alpha_1^{1ss} I_1(1ss1ss) + 4 \alpha_1^{0us} I_1(1ss0us) + 2 \alpha_1^{0ds} I_1(1ss0ds) \\
\alpha_1^{0ud} &= \lambda + \alpha_1^{1uu} I_1(0ud1uu) + \alpha_1^{0ud} I_1(0ud0ud) + 3 \alpha_1^{0us} I_1(0ud0us) + 3 \alpha_1^{0ds} I_1(0ud0ds) \\
\alpha_1^{0us} &= \lambda + \alpha_1^{1us} I_1(0us1uu) + 2 \alpha_1^{1ss} I_1(0us1ss) + \alpha_1^{0ud} I_1(0us0ud) + 3 \alpha_1^{0us} I_1(0us0us) + \alpha_1^{0ds} I_1(0us0ds) \\
&\quad + 2 \alpha_2^{1uu1ss} I_2(0us1uu1ss) + 2 \alpha_2^{0ss0ud} I_2(0us0ud1ss) \\
\alpha_1^{0ds} &= \lambda + 2 \alpha_1^{1ss} I_1(0ds1ss) + 2 \alpha_1^{0ud} I_1(0ds0ud) + 2 \alpha_1^{0us} I_1(0ds0us) + 2 \alpha_1^{0ds} I_1(0ds0ds) \\
&\quad + 4 \alpha_2^{1ss0ud} I_2(0ds0ud1ss) \\
\alpha_2^{1uu1ss} &= \lambda + 2 \alpha_1^{1ss} I_4(1ss1uu1ss) + 2 \alpha_1^{0ud} I_4(1uu1ss0ud) + 4 \alpha_1^{0us} I_3(1uu1ss0us) \\
&\quad + 4 \alpha_2^{1ss0ud} I_6(1uu1ss0ud1ss) \\
\alpha_2^{1ss0ud} &= \lambda + 4 \alpha_1^{1uu} I_4(0ud1ss1uu) + 2 \alpha_1^{1ss} I_4(1ss0ud1ss) + \alpha_1^{0ud} I_4(0ud1ss0ud) + 2 \alpha_1^{0us} I_3(1ss0ud0us) \\
&\quad + 2 \alpha_1^{0ds} I_3(1ss0ud0ds) + 2 \alpha_2^{1uu1ss} I_6(1ss0ud1ss1uu) + 2 \alpha_2^{1ss0ud} I_6(1ss0ud1ss0ud) \\
&\quad + 2 \alpha_3^{1uu1ss0us} I_8(1ss0ud1ss0us1uu) \\
\alpha_3^{1uu1ss0ds} &= \lambda + 2 \alpha_1^{1ss} I_9(0ds1ss1uu1ss) + 2 \alpha_1^{0ud} I_9(1uu0ds1ss0ud) + \alpha_1^{0us} (2 I_9(1uu0ds1ss0us) + \lambda) \\
&\quad + 4 I_9(1uu1ss0ds0us) + 2 \alpha_1^{0ds} I_9(0ds1ss1uu0ds) + 4 \alpha_2^{1ss0ud} I_10(1uu0ds1ss0ud1ss) 
\end{align*}
\]
Table I. S-wave dibaryon masses. Parameters of model: cutoff $\Lambda = 1.1$, gluon coupling constants $g_0 = 0.653$ and $g_1 = 0.292$. Quark masses $m_{u,d} = 410 \, MeV$ and $m_s = 557 \, MeV$.

| $S$ | $I$ | Quark content | $J$ | Dibaryon | Mass (MeV) |
|-----|-----|---------------|-----|----------|------------|
| 0   | 0   | uuuddd        | 1   | NN       | 1865       |
|     |     |               | 1   | $\Delta \Delta$ | 1834    |
| 1   | uuudd | N$\Delta$, $\Delta \Delta$ | 2   | 2020     |
| 2   | uuudd | N$\Delta$, $\Delta \Delta$ | 1   | 1984     |
| 3   | uuuuuu | 0, 2          | $\Delta \Delta$ | 2379 |
| $-1$ | 1/2 | uuudss        | 1   | $\Delta \Sigma$, $\Delta \Sigma^*$ | 1936 |
|     |     |               | 1   | $\Sigma \Sigma$, $\Sigma^* \Sigma^*$ | 1947 |
|     |     |               | 1   | $\Lambda \Lambda$ | 2024 |
| 3/2 | uuudss | $\Sigma \Sigma$, $\Sigma^* \Sigma^*$ | 1   | 2075     |
|     |     |               | 2   | $\Delta \Lambda$, $\Lambda \Sigma$ | 2157 |
|     |     |               | 2   | $\Lambda \Sigma$ | 2239 |
| 5/2 | uuussu | $\Delta \Sigma$, $\Delta \Sigma^*$ | 1   | 2101     |
| $-2$ | 0   | wuddss        | 0   | $\Sigma \Sigma$, $\Sigma^* \Sigma^*$ | 2118 |
|     |     |               | 1   | $\Lambda \Lambda$ | 2173 |
|     |     |               | 0   | $\Sigma \Xi$, $\Sigma^* \Xi$ | 2252 |
|     |     |               | 2   | $\Lambda \Xi$, $\Lambda \Xi^*$ | 2368 |
|     |     |               | 2   | $\Sigma \Xi$, $\Sigma^* \Xi^*$ | 2411 |
| 1   | uuudss | $\Sigma \Sigma$, $\Sigma^* \Sigma^*$, $\Lambda \Sigma$, $\Lambda \Sigma^*$ | 2138 |
|     |     |               | 1   | $\Delta \Xi$, $\Delta \Xi^*$ | 2292 |
|     |     |               | 1   | $\Lambda \Xi$, $\Lambda \Xi^*$ | 2336 |
| 2   | uuussu | $\Sigma \Sigma$, $\Sigma^* \Sigma^*$ | 0   | 2270     |
|     |     |               | 0   | $\Delta \Xi$, $\Delta \Xi^*$ | 2432 |
|     |     |               | 2   | $\Lambda \Xi$, $\Lambda \Xi^*$ | 2432 |
|     |     |               | 2   | $\Sigma \Xi$, $\Sigma^* \Xi^*$ | 2472 |
| $-3$ | 1/2 | wudssss       | 0   | $\Sigma \Xi$, $\Sigma^* \Xi^*$ | 2166 |
|     |     |               | 0   | $\Lambda \Xi$, $\Lambda \Xi^*$ | 2243 |
|     |     |               | 2   | $\Sigma \Xi$, $\Sigma^* \Xi^*$ | 2421 |
|     |     |               | 2   | $\Lambda \Xi$, $\Lambda \Xi^*$ | 2481 |
|     |     |               | 2   | $\Sigma \Omega$, $\Sigma^* \Omega$ | 2573 |
| 3/2 | uuussu | $\Sigma \Xi$, $\Sigma^* \Xi$, $\Sigma^* \Xi^*$ | 2195 |
|     |     |               | 1   | $\Delta \Omega$ | 2669 |
| $-4$ | 0   | udssss        | 1   | $\Xi \Xi$, $\Xi^* \Xi^*$ | 2428 |
|     |     |               | 1   | $\Lambda \Omega$ | 2553 |
| 1   | uusss | $\Xi \Xi$, $\Xi^* \Xi^*$ | 0   | 2509     |
|     |     |               | 0   | $\Sigma \Omega$, $\Sigma^* \Omega$ | 2706 |
|     |     |               | 2   | $\Sigma \Omega$, $\Sigma^* \Omega$ | 2706 |
|     |     |               | 2   | $\Xi \Xi$, $\Xi^* \Xi^*$ | 2720 |
| $-5$ | 1/2 | usssss        | 1   | $\Xi \Xi$, $\Xi^* \Xi^*$ | 2587 |
| $-6$ | 0   | ssssss        | 0, 2 | $\Omega \Omega$ | 3232 |
Table II. S-wave dibaryon masses. Parameters of model: cutoff $\Lambda = 11.0$, gluon coupling constants $g_0 = 0.647$ and $g_1 = 0.325$. Quark masses $m_{u,d} = 410 \text{ MeV}$ and $m_s = 557 \text{ MeV}$.

| $S$ | $I$ | Quark content | $J$ | Dibaryon | Mass (MeV) |
|-----|-----|---------------|-----|----------|------------|
| 0   | 0   | uuudddd       | 1   | NN       | 1848       |
|     |     |               | 1   | $\Delta \Delta$ | 1817 |
| 1   | 1   | uuuddd        | 2   | $N \Delta, \Delta \Delta$ | 1885 |
| 2   | 2   | uuwwud        | 1   | $N \Delta, \Delta \Delta$ | 1941 |
| 3   | 3   | uuwwuu        | 0, 2| $\Delta \Delta$ | 2278 |
| −1  | 1/2 | uuuddss       | 1   | $\Delta \Sigma, \Delta \Sigma^*$ | 1926 |
|     |     |               | 1   | $\Sigma \Sigma, \Sigma^* \Sigma^*$ | 1938 |
|     |     |               | 1   | $\Lambda \Lambda$ | 2016 |
| 3/2 | uuudds | 0   | $\Delta \Sigma^*$ | 1940 |
|     |     |               | 0   | $\Sigma \Sigma$ | 2063 |
|     |     |               | 2   | $\Delta \Sigma, \Delta \Sigma^*$ | 2054 |
|     |     |               | 2   | $\Lambda \Lambda$ | 2144 |
|     |     |               | 2   | $\Sigma \Sigma^*$ | 2218 |
| 5/2 | uuwwus | 1   | $\Delta \Sigma, \Delta \Sigma^*$ | 2057 |
| −2  | 0   | wuddss        | 0   | $\Sigma \Sigma, \Sigma^* \Sigma^*$ | 2115 |
|     |     |               | 0   | $\Lambda \Lambda$ | 2171 |
|     |     |               | 0   | $\Sigma \Xi$ | 2242 |
|     |     |               | 2   | $\Lambda \Xi^*$ | 2360 |
|     |     |               | 2   | $\Sigma \Sigma^*, \Sigma^* \Sigma^*$ | 2404 |
| 1   | uuuddss | 1   | $\Sigma \Sigma, \Sigma^* \Sigma^*, \Sigma \Lambda, \Lambda \Sigma^*$ | 2129 |
|     |     |               | 1   | $\Delta \Xi, \Delta \Xi^*$ | 2283 |
|     |     |               | 1   | $\Lambda \Xi^*$ | 2325 |
| 2   | uuussss | 0   | $\Sigma \Xi, \Sigma^* \Xi^*$ | 2241 |
|     |     |               | 0   | $\Delta \Xi^*$ | 2397 |
|     |     |               | 2   | $\Delta \Xi, \Delta \Xi^*$ | 2397 |
|     |     |               | 2   | $\Sigma \Sigma^*, \Sigma^* \Sigma^*$ | 2440 |
| −3  | 1/2 | uudsss        | 0   | $\Sigma \Xi, \Sigma^* \Xi^*$ | 2156 |
|     |     |               | 0   | $\Lambda \Xi$ | 2234 |
|     |     |               | 2   | $\Sigma^* \Xi, \Sigma^* \Xi^*$ | 2409 |
|     |     |               | 2   | $\Lambda \Xi^*$ | 2470 |
|     |     |               | 2   | $\Sigma \Omega$ | 2565 |
| 3/2 | uuussss | 1   | $\Sigma \Xi, \Sigma^* \Xi^*, \Sigma \Xi^* \Xi^*$ | 2170 |
|     |     |               | 1   | $\Delta \Omega$ | 2643 |
| −4  | 0   | udssss        | 1   | $\Xi \Xi, \Xi^* \Xi^*$ | 2409 |
|     |     |               | 1   | $\Lambda \Omega$ | 2535 |
| 1   | uussss | 0   | $\Xi \Xi, \Xi^* \Xi^*$ | 2478 |
|     |     |               | 0   | $\Sigma \Omega$ | 2667 |
|     |     |               | 2   | $\Sigma \Omega, \Sigma^* \Omega$ | 2667 |
|     |     |               | 2   | $\Xi \Xi^*, \Xi^* \Xi^*$ | 2683 |
| −5  | 1/2 | usssss        | 1   | $\Xi \Omega, \Xi^* \Omega$ | 2530 |
| −6  | 0   | ssssss        | 0, 2| $\Xi \Xi \Omega$ | 3093 |
Table III. Vertex functions and Ghew-Mandelstam coefficients.

| $i$ | $G_i^2(s_{kl})$ | $\alpha_i$ | $\beta_i$ | $\delta_i$ |
|-----|-----------------|------------|-----------|-----------|
| 0+  | $\frac{4g}{3} - \frac{8gm_{kl}^2}{3s_{kl}}$ | $\frac{1}{2}$ | $-\frac{1}{2} \frac{(m_k-m_l)^2}{(m_k+m_l)^2}$ | 0 |
| 1+  | $\frac{2g}{3}$ | $\frac{1}{3}$ | $\frac{4m_km_l}{3(m_k+m_l)^2} - \frac{1}{6} \frac{(m_k-m_l)^2}{(m_k+m_l)^2}$ | $-\frac{1}{6} \frac{(m_k-m_l)^2}{(m_k+m_l)^2}$ |
References.

1. R.L. Jaffe, Phys. Rev. Lett. 38, 195 (1977).
2. F. Wang, J.L. Ping, H.R. Pang and T. Goldman, Mod. Phys. Lett. A18, 356 (2003).
3. G.H. Wu, J.L. Ping, F. Wang and T. Goldman, Nucl. Phys. A673, 279 (2000).
4. M. Oka, K. Shimizu and K. Yazaki, Phys. Lett. B130, 365 (1983).
5. P.J.G. Mulders, A.T. Aerts and J.J. Swarts, Phys. Rev. Lett. 40, 1543 (1978).
6. A. Faessler, F. Fernandez, G. Lubeck et al., Nucl. Phys. A402, 555 (1983).
7. I.T. Obukhovsky and A.M. Kusainov, Phys. Lett. B238, 142 (1990).
8. E.M. Henley and C.A. Miller, Phys. Lett. B251, 453 (1991).
9. T. Kamae and T. Fujita, Phys. Rev. Lett. 38, 471 (1977).
10. K. Yazaki, Prog. Theor. Phys. Suppl. 91, 146 (1987).
11. F. Wang, G.H. Wu, L.J. Teng and T. Goldman, Phys. Rev. Lett. 69, 2901 (1992).
12. T. Goldman, K. Maltman, G.J. Stephenson Jr, J.-L. Ping and F. Wang, Mod. Phys. Lett. A13, 59 (1998).
13. Z.Y. Zhang, Y.W. Yu, X.Q. Yuan et al., Nucl. Phys. A670, 178 (2000).
14. V.B. Kopeliovich, Nucl. Phys. A639, 75 (1998).
15. P. LaFrance and E.L. Lomon, Phys. Rev. D34, 1341 (1986).
16. Y.W. Yu, Z.Y. Zhang and X.Q. Yuan, Commun. Theor. Phys. 31, 1 (1999).
17. Y.W. Yu, Z.Y. Zhang and X.Q. Yuan, High Energy Phys. and Nucl. Phys. 23, 859 (1999).
18. I.J.R. Aitchison, J. Phys. C3, 121 (1977).
19. J.J. Brehm, Ann. Phys. (N.Y.) 108, 454 (1977).
20. I.J.R. Aitchison and J.J. Brehm, Phys. Rev. D17, 3072 (1978).
21. I.J.R. Aitchison and J.J. Brehm, Phys. Rev. D20, 1119, 1131 (1979).
22. J.J. Brehm, Phys. Rev. D21, 718 (1980).
23. S.M. Gerasyuta and E.E. Matskevich, Phys. Rev. D76, 116004 (2007).
24. S.M. Gerasyuta and E.E. Matskevich, Int. J. Mod. Phys. E17, 585 (2008).
25. S.M. Gerasyuta and E.E. Matskevich, Yad. Fiz. 70, 1995 (2007).
26. A. De Rujula, H. Georgi and S.L. Glashow, Phys. Rev. D12, 147 (1975).
27. G.’t Hooft, Nucl. Phys. B72, 461 (1974).
28. G. Veneziano, Nucl. Phys. B117, 519 (1976).
29. E. Witten, Nucl. Phys. B160, 57 (1979).
30. O.A. Yakubovsky, Sov. J. Nucl. Phys. 5, 1312 (1967).
31. S.P. Merkuriev and L.D. Faddeev, Quantum Scattering Theory for System of Few Particles (Nauka, Moscow 1985) p. 398.
32. Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122, 345 (1961); 124, 246 (1961).
33. T. Appelqvist and J.D. Bjorken, Phys. Rev. D4, 3726 (1971).
34. C.C. Chiang, C.B. Chiu, E.C.G. Sudarshan and X. Tata, Phys. Rev. D25, 1136 (1982).
35. V.V. Anisovich, S.M. Gerasyuta and A.V. Sarantsev, Int. J. Mod. Phys. A6, 625 (1991).
36. G. Chew, S. Mandelstam, Phys. Rev. 119, 467 (1960).
37. V.V. Anisovich and A.A. Anselm, Usp. Fiz. Nauk 88, 287 (1966).
38. S.M. Gerasyuta, Z. Phys. C60, 683 (1993).
39. Q.B. Li, P.N. Shen, Z.Y. Zhang, Y.W. Yu, Nucl. Phys. A683, 487 (2001).
40. M. Bashkanov et al., Prog. Part. Nucl. Phys. 61, 304 (2008).
41. H. Pang, J. Ping, F. Wang, T. Goldman and E. Zhao, Phys. Rev. C69, 065207 (2004).