Strangeness \( s = -6 \) dibaryon

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The structure of \((\Omega\Omega)_{0^+}\) dibaryon with strangeness \( s = -6 \) is studied in the extended chiral \( SU(3) \) quark model, in which vector meson exchange dominates the short range interaction. The resonating group method (RGM) is adopted, in which the \( \Omega \) and \( CC \) (hidden color) channels are involved. The color screening effect and the effects of mixing of scalar mesons on \((\Omega\Omega)_{0^+}\) are also investigated.

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I. INTRODUCTION

Since the \( H \) dibaryon was theoretically predicted \( \[1\] \) by Jaffe in 1977, searching dibaryons both theoretically and experimentally has attracted worldwide attention. Various quark models were proposed to study their possible existence. Different from the deutron, whose property can be well explained by meson exchange mechanism on baryon level, dibaryon is supposed to be a color singlet multi-quark system with a sufficiently smaller size and dominance in quark-gluon degrees of freedom. Through these studies, we have enriched our knowledge of the strong interaction between quarks in the short-range region and some aspects about the basic theory of strong interactions, Quantum Chromodynamics (QCD), especially its nonperturbative effect.

Because of complexity in QCD nonperturbative effect at lower-energy region, one has to develop QCD-inspired models. The constituent quark model \( \[2, 3, 4, 5\] \) has been quite successful in understanding hadron spectroscopy and the short range behavior of hadron interactions even though we have not been able to derive the constituent quark model directly from QCD. Motivated by its success and combined with the chiral field theory, the model was then modified as the chiral quark model \( \[6\] \). Later on, as a generalization of the \( SU(2) \) linear \( \sigma \) model, a chiral \( SU(3) \) quark model was developed to describe systems with strangeness \( \[7\] \). The chiral \( SU(3) \) quark model has been quite successful in reproducing energies of baryon ground states, binding energy of deuteron, the nucleon-nucleon (NN) scattering phase shifts, and the hyperon-nucleon (YN) cross sections by performing the resonating group method (RGM) calculations. Based on this model, Zhang et al. \( \[8\] \) predicted that the \((\Omega\Omega)_{0^+}\) dibaryon with \( s = -6 \) is the most possible dibaryon candidate since its binding energy is large enough with small mean squared root radius in the model calculations. A suggestion to search its possible existence in heavy ion collision was also made.\( \[8\] \)

In Ref. \( \[9\] \), we extended our chiral \( SU(3) \) quark model to include the coupling between the quark and vector chiral fields. Such extension was made mainly based on the following facts. Firstly, in the study of NN interactions on quark level, the short-range feature can be explained by one gluon exchange (OGE) interaction and the quark exchange effect, while in the traditional one boson exchange (OBE) model on baryon level it comes from vector meson (\( \rho, \omega, K^* \) and \( \phi \)) exchanges. Secondly, Glozman and Riska proposed the boson exchange model \( \[10\] \), and found that the OGE can be replaced by vector-meson coupling in order to elucidate baryon structure. However, Isgur gave a critique on the boson exchange model and insisted that OGE govern the baryon structure \( \[11\] \). Furthermore, though a valence lattice QCD result shown by Liu et al did support the Goldstone boson exchange picture \( \[12\] \), Isgur considered such conclusion unjustified. Therefore, whether OGE or vector meson exchange is the right mechanism in describing the short range part of the strong interactions, or whether both of them are all important, is still a challenge. Nevertheless, our study on deuteron structure and the \( NN \) scattering phase shifts in the extended chiral \( SU(3) \) quark model \( \[13, 14\] \) did show that quark-vector chiral field coupling interactions can substitute the OGE mechanism on quark level. In the extended chiral \( SU(3) \) quark model, instead of the OGE interaction, the vector meson exchanges play a dominate role in the short range part of the quark-quark interactions. Since geometric size of a dibaryon is small, the short range feature of the interactions should be important in describing its structure. Hence, a further investigation on structure of \((\Omega\Omega)_{0^+}\) in the extended chiral \( SU(3) \) quark model should be helpful in resolving this issue.

In Refs. \( \[13, 14\] \), the CC (hidden color) channel and the color screening effect were investigated for \((\Delta\Delta)_{3^+}\) \((d^*)\) dibaryon. In Refs. \( \[15, 16\] \), the chiral \( SU(3) \) quark model and the extended chiral \( SU(3) \) quark model were used to study the baryon-meson interaction, in which different mixing of scalar mesons \( \sigma \) and \( \epsilon \) were discussed. It is interesting and important to study different mixing of scalar mesons for dibaryon system.

In this work, we will investigate structure of \((\Omega\Omega)_{0^+}\) dibaryon in the extended chiral \( SU(3) \) quark model

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A detailed analysis of the vector meson exchange, the CC channel, the color screening effect, and variance of the mixing angle between scalar mesons will be made. The paper is arranged as follows. A brief introduction of the extended chiral $SU(3)$ quark model is shown in section II. The results of the binding energies of $(\Omega\Omega)$ is shown in section II. The Hamiltonian of the system can be written as

$$H = \sum_i T_i - T_G + \sum_{i<j} V_{ij},$$

and

$$V_{ij} = V_{ij}^{\text{conf}} + V_{ij}^{\text{OGE}} + V_{ij}^{\text{ch}},$$

$$V_{ij}^{\text{vch}} = \sum_{a=0} V_{ij}^{a\nu}(\vec{r}_{ij}) + \sum_{a=0} V_{ij}^{a\nu}(\vec{r}_{ij}) + \sum_{a=0} V_{ij}^{a\nu}(\vec{r}_{ij}),$$

where $\sum T_i - T_G$ is the kinetic energy of the system, and $V_{ij}$ includes all the interactions between two quarks. $V_{ij}^{\text{conf}}$ is the confinement potential taken in quadratic form, $V_{ij}^{\text{OGE}}$ is the OGE interaction, and $V_{ij}^{\text{ch}}$ represents the interactions from the chiral field coupling, which, in the extended chiral $SU(3)$ quark model, includes the scalar meson exchange $V_{ij}^s$, the pseudo-scalar meson exchange $V_{ij}^ps$ and the vector meson exchange $V_{ij}^v$ potentials. In Eq. (2), the OGE is taken in the usual form $\hat{B}$, while the confinement potential is chosen in the quadratic form

$$V_{ij}^{\text{conf}} = -\lambda_c^s \lambda_c^s a_{ij}^0 - \lambda_c^s \lambda_c^s a_{ij} r_{ij}^2. \quad (4)$$

The quark-chiral field (scalar, pseudo-scalar and vector nonet mesons) induced interactions are

$$V_{ij}^{\nu a}(\vec{r}_{ij}) = -C(g_{ch}, m_{ps}, \Lambda_c)X_1(m_{ps}, \Lambda_c, r_{ij})\lambda_a(i)\lambda_a(j) + V_{ij}^{\nu a}(\vec{r}_{ij}), \quad (5)$$

$$V_{ij}^{\nu a}(\vec{r}_{ij}) = C(g_{ch}, m_{ps}, \Lambda_c) \frac{m_{ps}^2}{12 m_{ps} m_{ps}} \{X_2(m_{ps}, \Lambda_c, r_{ij})\}$$

$$\hat{S}_{ij} \lambda_a(i)\lambda_a(j), \quad (6)$$

$$V_{ij}^{\nu a}(\vec{r}_{ij}) = C(g_{ch}, m_{ps}, \Lambda_c) \frac{m_{ps}^2}{6 m_{qi} m_{qj}} \{X_2(m_{ps}, \Lambda_c, r_{ij})\}$$

$$\hat{S}_{ij} \lambda_a(i)\lambda_a(j) + V_{ij}^{\nu a}(\vec{r}_{ij}), \quad (7)$$

**II. FORMULATION**

**A. The Model**

In the extended chiral $SU(3)$ quark model, besides the nonet pseudo-scalar meson fields and the nonet scalar meson fields, the coupling between vector meson fields and quarks is also considered. With this generalization, the Hamiltonian of the system can be written as

$$H = \sum_i T_i - T_G + \sum_{i<j} V_{ij},$$

and

$$V_{ij} = V_{ij}^{\text{conf}} + V_{ij}^{\text{OGE}} + V_{ij}^{\text{ch}},$$

$$V_{ij}^{\text{vch}} = \sum_{a=0} V_{ij}^{a\nu}(\vec{r}_{ij}) + \sum_{a=0} V_{ij}^{a\nu}(\vec{r}_{ij}) + \sum_{a=0} V_{ij}^{a\nu}(\vec{r}_{ij}),$$

where $\sum T_i - T_G$ is the kinetic energy of the system, and $V_{ij}$ includes all the interactions between two quarks. $V_{ij}^{\text{conf}}$ is the confinement potential taken in quadratic form, $V_{ij}^{\text{OGE}}$ is the OGE interaction, and $V_{ij}^{\text{ch}}$ represents the interactions from the chiral field coupling, which, in the extended chiral $SU(3)$ quark model, includes the scalar meson exchange $V_{ij}^s$, the pseudo-scalar meson exchange $V_{ij}^{ps}$ and the vector meson exchange $V_{ij}^v$ potentials. In Eq. (2), the OGE is taken in the usual form $\hat{B}$, while the confinement potential is chosen in the quadratic form

$$V_{ij}^{\text{conf}} = -\lambda_c^s \lambda_c^s a_{ij}^0 - \lambda_c^s \lambda_c^s a_{ij} r_{ij}^2. \quad (4)$$

The quark-chiral field (scalar, pseudo-scalar and vector nonet mesons) induced interactions are

$$V_{ij}^{\nu a}(\vec{r}_{ij}) = -C(g_{ch}, m_{ps}, \Lambda_c)X_1(m_{ps}, \Lambda_c, r_{ij})\lambda_a(i)\lambda_a(j) + V_{ij}^{\nu a}(\vec{r}_{ij}), \quad (5)$$

$$V_{ij}^{\nu a}(\vec{r}_{ij}) = C(g_{ch}, m_{ps}, \Lambda_c) \frac{m_{ps}^2}{12 m_{ps} m_{ps}} \{X_2(m_{ps}, \Lambda_c, r_{ij})\}$$

$$\hat{S}_{ij} \lambda_a(i)\lambda_a(j), \quad (6)$$

$$V_{ij}^{\nu a}(\vec{r}_{ij}) = C(g_{ch}, m_{ps}, \Lambda_c) \frac{m_{ps}^2}{6 m_{qi} m_{qj}} \{X_2(m_{ps}, \Lambda_c, r_{ij})\}$$

$$\hat{S}_{ij} \lambda_a(i)\lambda_a(j) + V_{ij}^{\nu a}(\vec{r}_{ij}), \quad (7)$$

**TABLE I: Model parameters and the corresponding binding energies of Deuteron.**

|                     | Chiral SU(3) quark model | Extended chiral SU(3) quark model |
|---------------------|--------------------------|----------------------------------|
| $b_a$ (fm)          | 0.5                      | 0.45                             | 0.45 |
| $g_{NNs}$           | 13.67                    | 13.67                            | 13.67 |
| $g_{ch}$            | 2.621                    | 2.621                            | 2.621 |
| $g_{chv}$           | 0                        | 2.351                            | 1.972 |
| $f_{chv}/g_{chv}$   | 0                        | 0                                | 2/3  |
| $m_{\sigma}$ (MeV)  | 595                      | 535                              | 547  |
| $a_{uu}$ (MeV/fm$^2$)| 48.1                     | 48.0                             | 42.9  |
| $a_{us}$ (MeV/fm$^2$)| 63.7                     | 85.3                             | 78.9  |
| $a_{uu}^0$ (MeV/fm$^2$)| -43.6                   | -74.4                            | -65.3 |
| $a_{us}^0$ (MeV/fm$^2$)| -50.8                   | -100.2                           | -89.9 |
| $B_{def}$ (MeV)     | 2.13                     | 2.19                             | 2.14  |
respectively, where

\[
V_{s_a}^{\hat{s} \hat{s}}(\hat{r}_{ij}) = -C(g_{ch}, m_{s_a}, \Lambda_c) \frac{m_{s_a}^2}{4m_{q_i}m_{q_j}} G(m_{s_a} r_{ij})
\]

and

\[
V_{v_a}^{\hat{s} \hat{s}}(\hat{r}_{ij}) = -C(g_{chv}, m_{v_a}, \Lambda_c) \frac{3m_{v_a}^2}{4m_{q_i}m_{q_j}} \left(1 + \frac{f_{chv}}{g_{chv}} \frac{2(m_{q_i} + m_{q_j})}{3M_p}\right) \times G(m_{v_a} r_{ij}) - \frac{\Lambda_c^3}{m_{v_a}} G(\Lambda_c r_{ij}) \hat{L} \cdot (\vec{\sigma}_i + \vec{\sigma}_j) \lambda_a(i) \lambda_a(j),
\]

respectively, where

\[
C(g, m, \Lambda) = \frac{g^2}{4\pi} \frac{\Lambda m}{m^2 - \Lambda^2},
\]

\[
X_1(m, \Lambda, r) = Y(m r) - \frac{\Lambda}{m} Y(\Lambda r),
\]

\[
X_2(m, \Lambda, r) = Y(m r) - \frac{\Lambda^3}{m} Y(\Lambda r),
\]

\[
Y(x) = \frac{1}{x} e^{-x},
\]

\[
H(x) = (1 + \frac{3}{x} + \frac{3}{x^2}) Y(x),
\]

\[
G(x) = \frac{1}{x} (1 + \frac{1}{x}) Y(x),
\]

\[
\tilde{S}_{ij} = 3(\vec{\sigma}_i \cdot \hat{r})(\vec{\sigma}_j \cdot \hat{r}) - (\vec{\sigma}_i \cdot \vec{\sigma}_j),
\]

and \(M_p\) is a mass scale, taken as proton mass.

### B. Determination of parameters

In the model, \(g_{ch}\) is the coupling constant for scalar and pseudo-scalar chiral field coupling, which is determined according to the following relation:

\[
\frac{g_{N N}^2}{4\pi} = \frac{9}{25} \frac{m_u^2}{M_N^2} \frac{g_{ch}^2}{4\pi},
\]

and \(g_{N N}^2/4\pi\) is taken to be the experimental value, which is about 14. \(g_{chv}\) and \(f_{chv}\) are the coupling constants for vector coupling and tensor coupling of the vector meson field respectively. The meson masses \(m_{ps_a}\), \(m_{s_a}\), and \(m_{v_a}\) are taken to be the corresponding experimental values. Only the \(m_\sigma\) is treated as an adjustable parameter. According to the vacuum spontaneously breaking theory, its value should satisfy the following relation:

\[
m_\sigma^2 = (2m_u)^2 + m_\pi^2,
\]

which can be regarded as almost reasonable when the value of \(m_\sigma\) is located in the range of 550 \(\sim\) 650 MeV. In this work, values of \(g_{chv}\), \(f_{chv}\), and \(m_\sigma\) are taken to be the same as Ref. [9] which was used in the study of \(NN\) phase shift by fitting the binding energy of deuteron. In our calculation, \(\eta\) and \(\eta'\) mesons are mixed from flavor singlet \(\eta_0\) and flavor octet \(\eta_8\) mesons with

\[
\eta' = \eta_8 \sin \theta^{PS} + \eta_0 \cos \theta^{PS},
\]

\[
\eta = \eta_8 \cos \theta^{PS} - \eta_0 \sin \theta^{PS},
\]

in which the mixing angle is taken to be the experimental value with \(\theta^{PS} = -23^o\). Other model parameters in the calculation are fixed by the mass splitting among \(N,\Delta,\Lambda,\Sigma,\) and \(\Xi,\) and the stability conditions of the octet \((S = 1/2)\) and decuplet \((S = 3/2)\) baryons, which are all listed in Table I.

### III. RESULTS AND DISCUSSION

In Ref. [8], Zhang et al predicted the new dibaryon candidate \((\Omega\Omega)_{0+}\), which is a deeply bound state formed due to the quark exchange effect and the chiral-quark coupling and the fact that the quark exchange effect between two \(\Omega\) clusters makes these two \(\Omega\) closed up, because symmetry property of \((\Omega\Omega)_{0+}\) is very special [8]. There are only six baryon-baryon systems with this kind symmetry property, they are \((\Delta\Delta)_{ST=10},(\Delta\Delta)_{ST=03},(\Delta\Sigma)_{ST=3(1/2)},(\Delta\Sigma)_{ST=5(5/2)},(\Xi\Omega)_{ST=0(1/2)},\) and \((\Omega\Omega)_{ST=00}\). Since only \((\Omega\Omega)_{ST=00}\) can not decay through strong interactions among these six cases, in this sense \((\Omega\Omega)_{ST=00}\) should be the most interesting dibaryon candidate. In this section, we will further investigate the structure of \((\Omega\Omega)_{0+}\) dibaryon with respect to the vector meson exchange, the CC channel, the color screening effect, and the different mixing of scalar mesons.

#### A. the effect from vector mesons exchange

Structure of \((\Omega\Omega)_{0+}\) is studied in the extended chiral \(SU(3)\) quark model in which the vector meson exchanges are included. Our calculated results are shown in Table II, from which it can be seen that the effect from the vector meson fields is quite similar to that from the one gluon exchange (OGE) interaction. In the extended chiral \(SU(3)\) quark model, \((\Omega\Omega)_{0+}\) is still a deeply bound state with 135 \(\sim\) 158 MeV in binding energy when the vector meson exchanges control the short range part of the quark-quark interaction. The detailed analysis can be found in Ref. [21].

#### B. the effect from hidden color channel

In Ref. [12], the CC (hidden color) channel was investigated for the \(d^*\) dibaryon. The mixture of the \(L = 0\) and \(L = 2\) states shows that the effects of the tensor forces in
TABLE II: Binding energy $B$ and rms $r$ of the $(\Omega\Omega)_{0^{+}}$ dibaryon in the coupled channel calculation. $B = 2M_{\Omega} - E_{(\Omega\Omega)_{0^{+}}}$, $r = \sqrt{r^2}$.

|         | $B$(MeV) | $r$(fm) |
|---------|----------|---------|
| Chiral SU(3) quark model | 170.9 | 0.62 |
| Extended chiral set I | 135.6 | 0.60 |
| SU(3) quark model set II | 158.0 | 0.59 |

the OGE and chiral-quark field coupling were also considered. Their results show that the coupled channel effect is much stronger than the $L$ state mixing effect caused by the tensor interaction. It is interesting to see what is the CC channel effect on the $(\Omega\Omega)_{0^{+}}$ dibaryon. Hence, the hidden color channel will be considered with respect to the $(\Omega\Omega)_{0^{+}}$ dibaryon. According to Harvey’s work [18], the hidden color channel wave function can be constructed as

$$|CC\rangle_{str=-6,ST=00} = \frac{1}{2}|(\Omega\Omega)_{ST=00}\rangle + \frac{\hat{A}_{SFC}}{2}|(\Omega\Omega)_{ST=00}\rangle$$

where $\hat{A}_{SFC}$ stands for the antisymmetrizer in the spin-flavor-color space. The corresponding matrix elements of spin-flavor-color operators of coupled channels are given in Table III.

After performing an off-shell transformation [11], the results are tabulated in Table IV in the coupled-channel calculation. It is shown that the hidden color channel coupling only has very little effect on the binding energy of $(\Omega\Omega)_{0^{+}}$. Comparing with the study of $d^{*}$ dibaryon, in Refs. [13, 14], the results of the $d^{*}$ coupled-channel calculation show that the hidden color channel coupling has obvious effect on $d^{*}$ dibaryon. The binding energy of $d^{*}$ can be enhanced from 17 MeV to 23 MeV after the hidden color channel is included.

We make an analysis to see why the hidden color channel effect is so different for the case of $(\Omega\Omega)_{0^{+}}$ and $d^{*}$. From the matrix elements of the Hamiltonian in the generator coordinate method (GCM) calculation [21], which can describe the interaction between two clusters qualitatively, one can see that the energy of the hidden color state $|CC\rangle_{str=-6,ST=00}$ is much higher than that of $(\Omega\Omega)_{0^{+}}$ state, and the cross matrix elements between $(\Omega\Omega)_{0^{+}}$ and its corresponding hidden color state $|CC\rangle_{str=-6,ST=00}$ is relatively small. But for the case of $d^{*}$, the energy of the hidden color state in $(\Delta\Delta)_{ST=30}$ case are relatively not as high as in the $\Omega\Omega$ case, and the cross matrix elements between $(\Delta\Delta)_{ST=30}$ and its corresponding hidden color state is relatively large. All of these features can be understood based on the quite different flavor and spin structures of $(\Omega\Omega)_{0^{+}}$ and $d^{*}$.

C. color screening effect

It is well known that in the two-color-singlet-cluster system, the form and the strength of the confining potential do not affect the resultant quantities much. In concerning to the $(\Omega\Omega)_{0^{+}}$ structure, the hidden-color channel $CC$ is added to enlarge the model space. Once the $CC$ channel is considered, the color Van der Waals force

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TABLE III: Coefficients of spin-flavor-color operators.

| $\hat{O}_{ij}$ | $\Omega\Omega$ | $CC$ | $\Omega\Omega$ | $CC$ |
|----------------|--------------|------|--------------|------|
| $P_{36}$       | -3           | -12  | -21          |      |

$$\lambda_{i} \cdot \lambda_{j}$$

$$\hat{O}_{12} \quad -72 \quad 0 \quad -90$$
$$\hat{O}_{36} \quad 0 \quad 0 \quad -36$$
$$\hat{O}_{12} P_{36} \quad 8 \quad 32 \quad 2$$
$$\hat{O}_{36} P_{36} \quad -16 \quad 8 \quad 32$$
$$\hat{O}_{13} P_{36} \quad 8 \quad 32 \quad 20$$
$$\hat{O}_{16} P_{36} \quad 8 \quad -4 \quad 20$$
$$\hat{O}_{14} P_{36} \quad -4 \quad 2 \quad 35$$

$$\langle\hat{\sigma}_{i} \cdot \hat{\sigma}_{j}\rangle(\lambda_{8}^{(i)} \cdot \lambda_{8}^{(j)})$$

$$\hat{O}_{12} \quad 36 \quad 0 \quad -36$$
$$\hat{O}_{36} \quad -60 \quad 0 \quad -12$$
$$\hat{O}_{12} P_{36} \quad -4 \quad -16 \quad 44$$
$$\hat{O}_{36} P_{36} \quad 28 \quad 16 \quad 4$$
$$\hat{O}_{13} P_{36} \quad -4 \quad -16 \quad 20$$
$$\hat{O}_{16} P_{36} \quad -4 \quad 32 \quad 20$$
$$\hat{O}_{14} P_{36} \quad 12 \quad 24 \quad 0$$

$$\langle\hat{\sigma}_{i} \cdot \hat{\sigma}_{j}\rangle$$

$$\hat{O}_{12} \quad 27 \quad 0 \quad -27$$
$$\hat{O}_{36} \quad -45 \quad 0 \quad -9$$
$$\hat{O}_{12} P_{36} \quad -3 \quad -12 \quad 33$$
$$\hat{O}_{36} P_{36} \quad 21 \quad 12 \quad 3$$
$$\hat{O}_{13} P_{36} \quad -3 \quad -12 \quad 15$$
$$\hat{O}_{16} P_{36} \quad -3 \quad 24 \quad 15$$
$$\hat{O}_{14} P_{36} \quad 9 \quad 18 \quad 0$$

$$\lambda_{8}^{(i)} \cdot \lambda_{8}^{(j)}$$

$$\hat{O}_{12} \quad 36 \quad 0 \quad 36$$
$$\hat{O}_{36} \quad 36 \quad 0 \quad 36$$
$$\hat{O}_{12} P_{36} \quad -4 \quad -16 \quad -28$$
$$\hat{O}_{36} P_{36} \quad -4 \quad -16 \quad -28$$
$$\hat{O}_{13} P_{36} \quad -4 \quad -16 \quad -28$$
$$\hat{O}_{16} P_{36} \quad -4 \quad -16 \quad -28$$
$$\hat{O}_{14} P_{36} \quad -4 \quad -16 \quad -28$$

factor

$$\frac{1}{N} \quad \frac{1}{N} \quad \frac{1}{N}$$
TABLE IV: Binding energy $\mathcal{B}$ and rms $\overline{r}$ of the $(\Omega\Omega)^{0+}$ dibaryon in coupled channel calculation. $B = 2M_\Omega - E(\Omega\Omega)^{0+}$, $\overline{r} = \sqrt{\langle r^2 \rangle}$.

|                  | $\Omega\Omega(L = 0)$ | $\overline{r}$ (L = 0) |
|------------------|------------------------|------------------------|
| Chiral SU(3) quark model | $B$(MeV) 170.9          | $\overline{r}$(fm) 0.62 |
|                  | $\overline{r}$(fm) 0.62 |
| Extended chiral SU(3) quark model | $B$(MeV) 135.6          | $\overline{r}$(fm) 0.60 |
| set I            | $\overline{r}$(fm) 0.60 |
| set II           | $B$(MeV) 158.0          | $\overline{r}$(fm) 0.59 |
|                  | $\overline{r}$(fm) 0.59 |

TABLE V: Binding energy $\mathcal{B}$ of the $(\Omega\Omega)^{0+}$ dibaryon with $r^2$ and with error-function-like confinements in single channel calculation. $B = 2M_\Omega - E(\Omega\Omega)^{0+}$.

|                  | $r^2$ | Erf |
|------------------|-------|-----|
| Chiral SU(3) quark model | $B$(MeV) 170.9 | 163.6 |
|                  | $\overline{r}$(fm) 0.62 | 0.62 |
| Extended chiral SU(3) quark model | $B$(MeV) 135.6 | 126.1 |
| set I            | $\overline{r}$(fm) 0.60 | 0.61 |
| set II           | $B$(MeV) 158.0 | 149.1 |
|                  | $\overline{r}$(fm) 0.59 | 0.59 |

appears. To eliminate this unreasonable force, one may use an error-function-like confining potential to take the color screening effect, namely, the nonperturbative QCD effect, into account \cite{13}. Therefore, it is necessary to examine the stability of the resultant binding energy with respect to the form of the confining potential in the presence of the hidden-color state. For this purpose, we also adopt an error-function-like confining potential

$$V^{\text{erf-conf}}_{ij} = -\left(\lambda^a_i \lambda^a_j\right)_c \left(\alpha^{0}_{ij} + a_{ij} \text{erf} \left(\frac{r}{l_{cs}}\right)\right) , \quad (21)$$

where $l_{cs}$ denotes the color screening length, which is taken to be 2.0 fm in the $(\Omega\Omega)^{0+}$ structure calculation. The results are shown in Table VI, from which one sees that the resultant binding energy of $(\Omega\Omega)^{0+}$ are quite similar to those in the quadratic confinement case, namely, the bound state property would not change much when the color screening effect is counted.

D. The mixing of scalar mesons

The chiral SU(3) quark model has been widely used to study the baryon-meson interaction. When the model is extended to study the kaon-nucleon (KN) scattering, the scalar meson mixing between the flavor singlet and octet mesons is considered to explain the experimental phase shift. Therefore, the effect of the scalar meson mixing is also studied. In our calculation, scalar $\sigma$, $\epsilon$ mesons are mixed from $\sigma_0$ and $\sigma_8$ with

$$\sigma = \sigma_8 \sin \theta^S + \sigma_0 \cos \theta^S,$$

$$\epsilon = \sigma_8 \cos \theta^S - \sigma_0 \sin \theta^S,$$  

(22)

The mixing angle $\theta^S$ has been an open issue because the structure of the $\sigma$ meson is still unclear and controversial. Here we adopt two possible values as did in \cite{13,16}. One is the ideal mixing with $\theta^S = 35.264^\circ$. This is an extreme case in which the $\sigma$ exchange may occur only between u(d) quarks, while $\epsilon$ occurs between s quarks. Another mixing angle with $\theta^S = -18^\circ$ adopted was provided by Dai and Wu based on their investigation of a dynamically spontaneous symmetry breaking mechanism \cite{22}. The calculated results of $\Omega(\mathrm{SU(3)})$ are shown in Table VII of which the parameters are taken from Ref.\cite{16} by fitting KN scattering processes.

From the results one sees that in the extended chiral SU(3) quark model, the binding energy of $\Omega(\mathrm{SU(3)})$ has very big difference ( from 134 MeV to 15 MeV ) for different mixing angle of scalar mesons. When the mixing of scalar meson is taken to be the ideally mixing, that means there is no $\sigma$ exchange between two s quarks, the attraction from the $\sigma$ meson has reduced to zero, and thus the binding energy becomes much smaller. Comparing with the case of the chiral SU(3) quark model in which the binding energy of $\Omega(\mathrm{SU(3)})$ is about 60 MeV even the mixing angle is taken as ideal mixing, this means that in the extended chiral SU(3) quark model the short range repulsive interaction offered by $\phi$ meson exchange is stronger than that of OGE in the chiral SU(3) quark model. At the same time, in the case of $\theta^S = -18^\circ$, the attraction of the $\sigma$ meson is still play important role, and thus the binding energy becomes larger. In this sense, all of these features are useful for examining the model and its corresponding parameters.

Here we would like to point out that when the mixing angle of scalar meson is considered, the parameters are obtained by fitting KN scattering processes, not by fit-
ting NN and YN scattering processes. At the moment, we could not get a set of unified parameter to fit all of the scattering data of KN, NN and YN systems. However, we would like to see the effect on the structure of \(\Omega\Omega(0^+)\) from various set of parameters. The results tell us that different sets of parameters have large effect on the structure of \(\Omega\Omega(0^+)\) dibaryon, especially for the extreme case of the ideal mixing. From the above discussion, one can see that no matter which set of parameters is taken, even in the case of scalar meson ideal mixing the attraction from \(\epsilon\) is almost cancelled by the repulsion from \(\phi\) exchange, the \(\Omega\Omega(0^+)\) is always a bound state. This is because its symmetry structure is very special \(\mathbf{3}\), and the quark exchange effect of \(\Omega\Omega(0^+)\) is really important to make it always bound. For other systems without such special symmetry structure, the binding energies would also changed a lot with different sets of parameters. For some weakly bound systems, the structure property could be changed from bound state to unbound state. There would be no such stable bound property like \(\Omega\Omega(0^+)\) in the systems without such special symmetry property.

IV. SUMMARY

In this work, the structure of \(\Omega\Omega(0^+)\) dibaryon with strangeness \(s = -6\) is studied in the extended chiral \(SU(3)\) quark model. The model space is enlarged by including the CC channel. The calculations are performed by solving a coupled-channel RGM equation. Firstly, the vector meson exchange effect on \((\Omega\Omega)_{0^+}\) dibaryon is studied on quark level. The results show that \((\Omega\Omega)_{0^+}\) is still a deeply bound state when the vector meson exchanges control the short range part of the quark-quark interaction, which is quite similar to the results obtained from the chiral \(SU(3)\) quark model. Secondly, the effect from hidden color channel on \(\Omega\Omega(0^+)\) dibaryon is studied. It is found that the energy of the hidden color state \(|CC\rangle_{stry=-6, ST=0}\) is much higher than that of \((\Omega\Omega)_{0^+}\) state, and the cross matrix elements between \((\Omega\Omega)_{0^+}\) and its corresponding hidden color state \(|CC\rangle_{stry=-6, ST=0}\) is relatively small, which explains why the CC channel has little effect on the binding energy of \(\Omega\Omega(0^+)\) dibaryon in contrast to the deltaron dibaryon case with a different situation. In addition, the error function confinement potential is considered, from which the resultant binding energy of \((\Omega\Omega)_{0^+}\) is quite similar to that in the quadratic confinement case. Namely, the bound state property would not change much when the color screening effect is counted. Finally, the effects of scalar meson mixing on \(\Omega\Omega(0^+)\) dibaryon are also investigated. The result shows that the binding energy of the \(\Omega\Omega(0^+)\) has changed substantially with different scalar meson mixings, which becomes larger with \(\theta^S = -18^\circ\) and smaller in the ideal mixing with \(\theta^S = 35.264^\circ\). It should be noted that our current analysis of \(\Omega\Omega(0^+)\) dibaryon is based on the results from the fit to KN scattering processes, in which the scalar meson mixing angle should be considered. A further study of the \(\Omega\Omega(0^+)\) dibaryon structure should be based on results obtained from a fit to KN, NN and YN scattering processes simultaneously, at least from a fit to NN and YN scattering processes, which will be considered in the near future.

Our conclusion is that the \(\Omega\Omega(0^+)\) dibaryon is always a bound state regardless which set of parameters is used in the extended chiral \(SU(3)\) quark model due to its unique symmetry property. Therefore, the \(\Omega\Omega(0^+)\) is the most interesting dibaryon candidate.

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