THE POSSIBLE DI-OMEGA DIBARYON IN QUARK CLUSTER MODEL*

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The mixing of scalar mesons is introduced into the baryon-baryon system in the chiral SU(3) quark model to further dynamically investigate the Di-omega state by using the same parameters as those in reasonably describing the experimental hyperon-nucleon and nucleon-nucleon scattering data. Two different mixings of scalar mesons, the ideal mixing and 19° mixing, are discussed, and compared with no mixing. The results show that it is still deeply bound state if 19° mixing is adopted, the same as those of no mixing. However, for ideal mixing, the binding energy is reduced quite a lot, yet it is still a bound state.

Keywords: Dibaryon; Few-body system; Chiral symmetry.

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1. Introduction

Searching dibaryons both theoretically and experimentally has attracted worldwide attention since Jaffe's first prediction of H dibaryon in 1977.¹ Various quark models were used to study the possible existence of dibaryons. One of the most successful models is the chiral SU(3) quark model,² which was proposed by generalizing the idea of σ model³ at nuclear level to the flavor SU(3) case at quark level²⁻⁵. In this model, the nonet pseudoscalar and nonet scalar mesons exchanges are considered in describing the medium and long range parts of the interactions, and the one gluon

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exchange (OGE) for the short range repulsive interaction. By using the resonating group method (RGM), the energies of the baryon ground states, the nucleon-nucleon (NN) scattering phase shifts and the hyperon-nucleon (YN) cross sections have been reproduced reasonably in the chiral $SU(3)$ quark model.² Furthermore, many possible dibaryon states have also been predicted.^{6–9} More importantly, the authors⁶ found that the most interesting bound state is the Di-Omega dibaryon, $(\Omega\Omega)_{ST=00}$, and their results show that it is the deeply bound state with narrow decay width. Then the model was generalized into the extended chiral $SU(3)$ quark model¹⁰ and got similar result for this state.¹¹ Here we should emphasize that for all these above works, the mixing of scalar mesons wasn't considered, but the mixing of pseudoscalar mesons has been considered,

$$\begin{aligned}\eta &= \pi_8 \cos \theta_{ps} - \pi_0 \sin \theta_{ps}, \\ \eta' &= \pi_8 \sin \theta_{ps} + \pi_0 \cos \theta_{ps},\end{aligned}\tag{1}$$

where the θ_{ps} is mixing angle of singlet π_0 and octet π_8 pseudoscalar mesons, and the experimental θ_{ps} is taken to be -23° .

In recent years, the kaon-nucleon (KN) scattering process has aroused particular interest. At quark level, the authors failed to describe the KN scattering data using the RGM calculation.¹² In their model, the short-range interaction from OGE, and medium and long-range interaction from the parameterized π and σ field exchanges are included. Their results show that the attractive force from σ meson exchange is too strong to describe the KN data. In order to solve this difficulty, Huang et al. introduced the mixing of scalar mesons in the chiral $SU(3)$ quark model, and found that the experimental KN data can be reasonably described.¹³ It is clear that the success¹³ is because of the introduction of the mixing of scalar mesons in the chiral $SU(3)$ quark model, thus the attractive contribution from σ exchange between K and N can be reduced. Inspired by this achievement, the ideal mixing of scalar mesons was further introduced into baryon-baryon system and found that the NN and YN interactions can also be reasonably described.¹⁴ Thus, in the present work, using the same parameters as those in Ref. 14 for scattering processes, we will further dynamically investigate the Di-omega dibaryon by solving RGM equation for different mixing cases.

2. The Chiral $SU(3)$ Quark Model

The chiral $SU(3)$ quark model has been described in the literature.² Here we just give the salient feature. The total Hamiltonian of baryon-baryon system is

$$H = \sum_{i=1}^6 T_i - T_G + \sum_{i<j=1}^6 V_{ij}\tag{2}$$

here T_G is the kinetic energy operator of the center of mass motion, and V_{ij} represents the quark-quark interaction,

$$V_{ij} = V_{ij}^{OGE} + V_{ij}^{conf} + V_{ij}^{ch},\tag{3}$$

where V_{ij}^{OGE} is the OGE interaction, and V_{ij}^{conf} is the confinement potential. V_{ij}^{ch} represents the chiral fields induced effective quark-quark potential

$$V_{ij}^{\text{ch}} = \sum_{a=0}^8 V_{\sigma_a}(\mathbf{r}_{ij}) + \sum_{a=0}^8 V_{\pi_a}(\mathbf{r}_{ij}). \quad (4)$$

which is derived from the interaction Lagrangian

$$\mathcal{L}_I = -g_{ch} \bar{\psi} \left(\sum_{a=0}^8 \sigma_a \lambda_a + i \sum_{a=0}^8 \pi_a \lambda_a \gamma_5 \right) \psi. \quad (5)$$

The initial input parameters are the harmonic-oscillator width parameter b_u , and the quark masses m_u and m_s . The coupling constant g_{ch} for scalar and pseudo-scalar chiral field coupling is fixed by experimental value. All meson masses, m_{ps} and m_s , are taken to be the experimental values,¹⁵ except for σ and m_κ mesons which are treated as an adjustable parameters. The cut-off mass Λ indicate the chiral symmetry breaking scale. After the parameters of chiral fields are fixed, the one gluon exchange coupling constants can be determined by the mass splits between different baryons. The confinement strength is fixed by the stability conditions of baryons. Since the aim of the present work is to study the mixing problem of scalar mesons, the σ and ϵ mesons are mixed by

$$\begin{aligned} \sigma &= \sigma_8 \sin \theta_s + \sigma_0 \cos \theta_s, \\ \epsilon &= \sigma_8 \cos \theta_s - \sigma_0 \sin \theta_s. \end{aligned} \quad (6)$$

here θ_s is the mixing angle of singlet σ_0 and octet σ_8 scalar mesons. Two cases will be considered: one is the ideal mixing with $\theta_s = 35.264^\circ$, in which the σ meson only acts on the u(d) quark, and ϵ meson on the s quark. Actually, some works using chiral dynamics show that the σ exchange contribution to the KN interaction is negligible,¹⁶ which means the σ meson only acts on the u(d) quark; and another is $\theta_s = 19^\circ$ mixing, which was predicted from chiral unitary picture by Oller's work,¹⁷ showing that the κ , $a_0(980)$, σ and the $f_0(980)$ resonances constitute the lightest

Table 1. Model parameters. The meson masses: $m_\pi = 138$ MeV, $m_K = 495$ MeV, $m_\eta = 549$ MeV, $m_{\eta'} = 957$ MeV, $m_{\sigma'} = m_\epsilon = 980$ MeV, and the cutoff mass $\Lambda = 1100$ MeV for all mesons.

	Chiral SU(3) quark model		
	Set I	Set II	Set III ⁶
m_σ (MeV)	560	644	625
m_κ (MeV)	780	1050	958
θ_{ps}	-23°	-23°	-23°
θ_s	35.264°	19°	0°
b_u (fm)	0.5	0.5	0.505
m_u (MeV)	313	313	313
m_s (MeV)	470	470	470
g_{ch}	2.62	2.62	2.62

Table 2. Binding energy $B = 2M_\Omega - E_{(\Omega\Omega)_{ST=00}}$ and mean squared root radius $\overline{R} = \sqrt{\langle r^2 \rangle}$ of the $(\Omega\Omega)_{ST=00}$ dibaryon

	Chiral SU(3) quark model		
	Set I	Set II	Set III ⁶
B (MeV)	26	84	116
$\overline{R}$ (fm)	0.82	0.67	0.63

scalar nonet and the mixing angle between the singlet and the octet $I = 0$ states is $\theta_s = 19 \pm 5^\circ$. The resultant model parameters are tabulated in Table 1, and the parameters for no mixing case from Ref. 6 are also given for comparison.

3. Results and discussion

Using the same parameters as those in Ref. 14 for scattering processes, we further dynamically investigate the Di-omega dibaryon by solving RGM equation for different mixing cases. The predicted results are listed in Table 2, and results for no mixing case from Ref. 6 are also given. From Table 2, we can see that for no mixing (Set III), the binding energy is quite large.⁶ However, for ideal mixing (Set I), although $(\Omega\Omega)_{ST=00}$ is still a bound state, yet the binding energy is reduced quite a lot, since there is no attractive contribution from σ meson exchange between s quarks. For the $\theta_s = 19^\circ$ mixing (Set II), we make an detailed analysis and find that both σ and ϵ meson exchanges contribute the attractive interactions, thus the binding energy still quite large for this mixing case, which is very similar to the case of no mixing. In summary, the possible Di-omega dibaryon are further predicted in this work with different mixing, especilly we find that it is still a deeply bound state when 19° mixing of scalar mesons is adopted.

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