

Six-quark structure of $d^*(2380)$ in a chiral constituent quark modelQi-Fang Lü,^{1,2,*} Fei Huang,² Yu-Bing Dong,^{1,2,3} Peng-Nian Shen,^{4,1,3} and Zong-Ye Zhang^{2,1,3}¹*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China*²*School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 101408, China*³*Theoretical Physics Center for Science Facilities (TPCSF), CAS, Beijing 100049, China*⁴*College of Physics and Technology, Guangxi Normal University, Guilin 541004, China*

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The structure of $d^*(2380)$ is restudied with the single cluster structure in the chiral SU(3) quark model which has successfully been employed to explain the $N - N$ scattering data and the binding energy of deuteron. The binding behavior of such a six quark system is solved by using a variational method. The trial wave function is chosen to be a combination of a basic spherical symmetric component of $[(0s)^6]_{\text{orb}}$ in the orbital space with $0\hbar\omega$ excitation and an inner structural deformation component of $[(0s)^5(1s)]_{\text{orb}}$ and $[(0s)^4(0p)^2]_{\text{orb}}$ in the orbital space with $2\hbar\omega$ excitation, both of which are in the spatial $[6]_{\text{orb}}$ symmetry. It is shown that the mass of the system is about 2356 MeV, which is qualitatively consistent with the result both from the two-cluster configuration calculation and from the data measured by the WASA Collaborations. When the meson exchange interactions are absent, the attraction is insufficient to form a stable state below the $\Delta\Delta$ threshold. This result tells us that as long as the medium-range interaction due to the chiral symmetry consideration is properly introduced, the mass of the system will be reduced in a rather large extent. It also implies that the observed d^* is a six-quark bound state with respect to the $\Delta\Delta$ threshold, which again supports the conclusion that d^* is a hexaquark dominant state.

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I. INTRODUCTION

During past years, a resonant structure $d^*(2380)$ has been reported in the double-pion fusion reactions $pn \rightarrow d\pi^0\pi^0$ and $pn \rightarrow d\pi^+\pi^-$ by the WASA-at-COSY collaborations [1,2]. Later on, this resonance has also been observed in $pn \rightarrow pn\pi^0\pi^0$, $pn \rightarrow pp\pi^-\pi^0$, $pd \rightarrow {}^3\text{He}\pi^0\pi^0$, $pd \rightarrow {}^3\text{He}\pi^+\pi^-$, $dd \rightarrow {}^4\text{He}\pi^0\pi^0$, and $dd \rightarrow {}^4\text{He}\pi^+\pi^-$ reactions [3–8], and further confirmed by incorporating the newly measured analyzing power data into the partial wave analysis [8,9]. The data show that $d^*(2380)$ has a mass of 2380 MeV, a width of $\Gamma \approx 70$ MeV, and an isospin-spin-parity of $I(J^P) = 0(3^+)$ [10].

Since the mass of $d^*(2380)$ is away from the thresholds of the $\Delta\Delta$, $\Delta N\pi$, $NN\pi\pi$ channels, the threshold effect is expected to be smaller than that in some exotic XYZ states [11,12]. The structural uncertainty in studying $d^*(2380)$ would be much smaller. On the other hand, although observed mass is higher but not much higher than the $\Delta N\pi$ and $NN\pi\pi$ thresholds, its width is only 70 MeV, which is much smaller than the width of two Δ s. The fact that the width of $d^*(2380)$ is remarkably small excludes the scenario of the naïve $\Delta\Delta$ molecular structure where the Δ s are color singlet particles and indicates that the effect of the hidden-color channel should be significant [13,14]. Due to these extraordinary properties of $d^*(2380)$, it becomes a good platform to reveal some information about the new structure in the hadronic system.

The properties of dibaryon states were first discussed by Dyson and Xuong in 1964 in the framework of SU(6) symmetry where no dynamics is considered [15]. Since then, various theoretical investigations on dibaryon have been performed. Recently, Gal and Garcilazo studied the $\pi N\Delta$ system in a Faddeev type three-body calculation and dynamically generated a pole where its mass and width are close to the data of WASA, although some approximations were employed [16,17]. In Ref. [18], H. Huang *et al.*, investigated the binding behavior of the $\Delta\Delta$ system in a coupled channel calculation in the framework of the chiral SU(2) model and obtained a binding energy of about 71 MeV and a width of about 150 MeV, which is much larger than the reported data. Even in a QCD sum rule calculation, one can also get a mass of 2.4 ± 0.2 GeV [19]. However, a recent calculation by using a constituent quark model with the one-gluon-exchange (OGE) and confinement interactions only showed that the six $u - d$ quark system with the $[6]$ symmetry in the orbital space should not be bound with respect to the $\Delta\Delta$ threshold [20].

It is noteworthy that in a much earlier calculation in the chiral SU(3) quark model, the binding property of the $\Delta\Delta$ system with $I(J^P) = I(S^P) = 0(3^+)$, where I, J (or S), and P stand for the isospin, spin, and parity, respectively, was studied by including a hidden color (CC) component, and a bound state with a binding energy of 40–80 MeV relative to the threshold of the $\Delta\Delta$ channel was predicted [14,21]. After the new discovery by the WASA-at-COSY collaborations, more detailed calculations for such a state have been performed on the base of the chiral SU(3) quark

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model and extended chiral SU(3) quark model [22–24]. In the framework of the resonating group method (RGM), the mass and wave function of the state are obtained by dynamically solving the coupled-channel equations where the coupling of the $\Delta\Delta$ channel with a hidden color channel has been considered. The partial decay widths of the $d^* \rightarrow d\pi\pi$, $d^* \rightarrow NN\pi\pi$ and $d^* \rightarrow NN\pi$ processes are evaluated in terms of the extracted wave function, and the total width of about 71 MeV of d^* , which coincides with the averaged experimental value of 75 MeV, is obtained [23,25,26]. It is shown that due to a large CC component in the system, the resultant mass and width are compatible with the data, namely, such a component plays an essential role in interpreting the observed characters of d^* , especially its narrow width. Thus, one would conjecture that $d^*(2380)$ might be a hexaquark dominated exotic state.

Inspired by a large CC component in $d^*(2380)$ and a small size in the coordinate space, it is reasonable to study the $(IS) = (03)$ six quark system in an alternative model space with a single cluster configuration (SCC). On the other hand, according to Harvey's relation from the group theory [27], in a six quark system, single-cluster configurations and two-cluster configurations (TCC) can transform each other via Fierz transformation. In this sense, if $d^*(2380)$ is a hexaquark dominated state, the major characters obtained in the TCC calculation, say the binding behavior and the narrow width, should also appear in the SCC calculation. This is because that by rearranging the form of the wave function obtained in the TCC calculation, one finds that the main component in TCC is a genuine six-quark configuration $(0s)^6[6]_{\text{orb}}[111111]_{\text{SIC}}$, or called hexaquark configuration. Therefore, the main aim of this paper is to see whether SCC has similar properties as those obtained in the TCC calculation. In this work, we would restudy such a six quark system in a SCC calculation with the same chiral SU(3) quark model and the same model parameters. The trivial wave function consists of a $(0s)^6[6]_{\text{orb}}[111111]_{\text{SIC}}$ component together with a component with a $2\hbar\omega$ -excitation, which is orthogonal to the wave function of the excited center of mass motion.

It should particularly be emphasized that due to the importance of the chiral symmetry in the strong interaction, such a symmetry should be restored in the Lagrangian of the hadronic system, which leads to the well-known σ model [28]. In the QCD-inspired constituent quark model, the spontaneous symmetry breaking of vacuum generates the Goldstone boson, and consequently, the constituent quark mass. Based on this Goldstone theory, the Goldstone boson has to be introduced if a constituent quark model is adopted. That is why a chiral SU(3) constituent quark model was proposed. With such a model, most data of the ground state properties of baryons, the baryon spectrum, the baryon-baryon scattering phase shifts and cross sections, and some binding behaviors of two-hadron systems, for instance, deuteron and H particle, etc. can be explained

in quite good extent [29], although this model is somehow a preliminary attempt to modeling the nonperturbative effect of QCD (NPQCD). However, if in a constituent quark model, the interquark interaction includes only the OGE and confinement terms (naive OGE quark model), the scattering and binding behaviors between nucleons might not be reasonably explained, because the medium-range NPQCD, which is described by the Goldstone boson exchange in our chiral constituent quark model, is missing. Therefore, another goal in this paper is to see that if the interactions arising from the Goldstone boson exchange are incorporated into the naive OGE quark model, whether the conclusion in Ref. [20] could be changed.

The paper is organized as follows. In Sec. II, the formalism for both interaction and wave functions is briefly introduced. The results and discussions are given in Sec. III. Finally, a short summary is provided in Sec. IV.

II. BRIEF FORMULISM

A. Interaction

The interactive Lagrangian between the quark and chiral field in the chiral SU(3) constituent quark model can be written as

$$\mathcal{L}_I^{\text{ch}} = -g_{\text{ch}}\bar{\psi}\left(\sum_{a=0}^8\lambda_a\sigma_a + i\gamma_5\sum_{a=0}^8\lambda_a\pi_a\right)\psi, \quad (1)$$

where g_{ch} is the coupling constant of quark with the chiral field, ψ is the quark field, and σ_a and π_a ($a = 0, 1, \dots, 8$) are the scalar and pseudoscalar nonet chiral fields, respectively. Then, the interactive Hamiltonian can be obtained by,

$$\mathcal{H}_I^{\text{ch}} = g_{\text{ch}}F(\mathbf{q}^2)\bar{\psi}\left(\sum_{a=0}^8\lambda_a\sigma_a + i\gamma_5\sum_{a=0}^8\lambda_a\pi_a\right)\psi, \quad (2)$$

where the form factor $F(\mathbf{q}^2)$ is introduced to imitate the structures of the chiral fields. The form of $F(\mathbf{q}^2)$ is usually taken as

$$F(\mathbf{q}^2) = \left(\frac{\Lambda^2}{\Lambda^2 + \mathbf{q}^2}\right)^{1/2}, \quad (3)$$

with Λ being the cutoff mass, which corresponds to the scale of the chiral symmetry breaking [30–32]. From this Hamiltonian, the chiral field caused quark-quark interaction V^{σ_a} and V^{π_a} , which mainly provide the medium-range interaction from NPQCD, can easily be derived. To reasonably describe the short-range interaction from the perturbative QCD (pQCD), one-gluon-exchange (OGE) interaction V^{OGE} is still employed. It should be emphasized that double counting does not occur between the OGE and chiral field caused interactions, because the former is a short-range interaction from pQCD and the latter describes

the medium-range interaction from NPQCD, respectively. Meanwhile, a phenomenological confining potential V^{conf} is again adopted to account for the long-range interaction from NPQCD. Consequently, the total Hamiltonian of a six-quark system in the chiral SU(3) quark model, it can be given by

$$H = \sum_{i=1}^6 (m_q)_i + \sum_{i=1}^6 T_i - T_G + \sum_{j>i=1}^6 (V_{ij}^{\text{OGE}} + V_{ij}^{\text{conf}} + V_{ij}^{\text{ch}}), \quad (4)$$

where $(m_q)_i$ denotes the mass of the i th quark, the T_i and T_G are the kinetic energy operators of the i th quark and the center of mass motion (CM), respectively, V_{ij}^α with $\alpha = \text{OGE, conf, ch}$ denote the OGE, confinement, and chiral field induced interactions between the i th and j th quarks, respectively,

$$V_{ij}^{\text{ch}} = \sum_{a=1}^8 V_{ij}^{\sigma_a} + \sum_{a=1}^8 V_{ij}^{\pi_a}. \quad (5)$$

The explicit expressions of these potentials can be found in Ref. [29]. In this work, a chiral SU(3) quark model with a linear confining potential is employed to reveal the binding character of the concerned six-quark system with a SCC structure, and corresponding model parameters are listed in Table I, in which the coupling constant g_{ch} of the chiral field with quarks is determined by the experimental value of the $NN\pi$ coupling constant $g_{NN\pi}$, the coupling constant g_u of the gluon with quarks is fixed by the mass difference between N and Δ , the confining strength a_{uu}^c of the OGE potential is obtained by satisfying the stability condition of the nucleon (N), the zero-point energy a_{uu}^0 is fixed by the mass of N , the masses of the exchanged bosons are chosen from the empirical masses of relevant mesons and by fitting the data of the $N - N$ scattering and the binding energy of the deuteron. These values are exactly the same as those in our previous two channel RGM calculations except the values of a_{uu}^c and a_{uu}^0 , because here the quadratic confinement is replaced by a linear one [24]. The reason for choosing a linear confining potential is that due to the NPQCD effect, the confining potential prefers a linear form rather than a quadratic one. According to the lattice calculation, it even tends to a color screened form whose

TABLE I. Model parameters of chiral SU(3) quark model with linear confinement. The masses of exchanged mesons are $m_\sigma = 980$ MeV, $m_\rho = 980$ MeV, $m_\pi = 138$ MeV, $m_\eta = 549$ MeV, $m_\eta' = 957$ MeV, respectively. The cutoff mass is $\Lambda = 1100$ MeV.

b_u (fm)	m_u (MeV)	g_u^2	g_{ch}	m_σ (MeV)	a_{uu}^c (MeV/fm)	a_{uu}^0 (MeV)
0.5	313	0.766	2.621	595	87.5	-77.4

strength is weaker than that of the linear one at the larger separation between quarks. Moreover, in the hadronic spectrum study, because the mass scale is about GeV, the NPQCD effect is surely non-negligible, as a consequence, the spectrum will be sensitive to the form of the confining potential, especially in the SCC calculation. In order to provide a meaningful prediction about the binding behavior of d^* , it is better to take a linear form or even color screened form for the confining potential. It should be specially mentioned that in the nucleon-nucleon case, since the intercluster interaction intervenes between two color singlets, the choice of the different confining potential will not cause visible effects in the $N - N$ interaction. Namely, using a linear confining potential instead of a quadratic one will not affect either scattering phase shifts or binding results between nucleons [24,29]. Based on the above reasoning, we can ensure that the model with a linear confining potential still possesses the prediction power.

B. Wave function

Now, we select the trial wave function of the six-quark system in the model space of SCC. Since the ground state of the six-quark system with $(IS) = (03)$ and $L = 0$ in this model space has the symbolic form of

$$\psi_1 = ((0s)^6 [6]_{\text{orb}} [111111]_{\text{SFC}})_{(IS)=(03)}, \quad (6)$$

where $(0s)$ represents a $(0s)$ orbital wave function of the harmonic oscillator with b_1 being the size parameter, the total orbital wave function has a $[6]$ symmetry, and the total wave function in the spin-flavor-color space has a $[111111]$ symmetry. As shown in Ref. [33], this configuration is not adequate to describe this system, therefore the components with higher excitations should be included. On the other hand, the result in the TCC calculation shows that the CC component in the wave function of d^* has a rather large fraction, about 2/3. By reorganizing such a wave function (refer to the right panel of Fig. 1 in Ref. [22]) to form a $((0s)^6 [6]_{\text{orb}} [111111]_{\text{SFC}})_{(IS)=(03)}$ type wave function, one sees that the obtained wave function has a large fraction of about 80% in the total wave function. It implies that the main character of the observed structure by the WASA-at-COSY collaboration should also appear in the SCC calculation. If the structure proposed in our previous TCC calculation is reasonable, the curve in the right panel of Fig. 1 tells us that one needs at least an additional component of the wave function with one node in radial, namely a $(1s)$ radially excited wave function. Thus, in the lowest order approximation, we could adopt an additional wave function which has $2\hbar\omega$ excitation to supplement the inadequacy of ψ_1 in describing d^* . Now, we pick up all the wave functions which have $2\hbar\omega$ radial excitation

$$((0s)^5 (1s) [6]_{\text{orb}} [111111]_{\text{SFC}})_{(IS)=(03)},$$

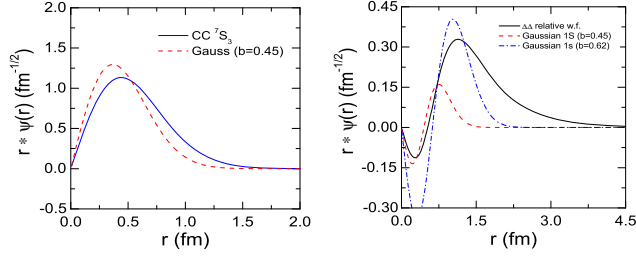


FIG. 1. Wave functions in the TCC calculation. The left panel shows the 7S_3 wave function of the CC channel, and the right panel presents the remained wave function after subtracting a ψ_1 wave function and a Gaussian function with (1s) excitation.

and

$$((0s)^4(0p)^2[6]_{\text{orb}}[111111]_{\text{SIC}})_{(IS)=(03)},$$

where (0p) and (1s) denote the orbital wave functions of a quark moving in the (0p) and (1s) orbits, respectively, which also take the harmonic oscillator form with a size parameter of b_2 . Their orbital parts can be written explicitly as

$$(0s)^5(1s)[6]_{\text{orb}} = \sqrt{\frac{1}{6}} \sum_{i=1}^6 [(0s)^5(1s)_i],$$

and

$$(0s)^4(0p)^2[6]_{\text{orb}} = \sqrt{\frac{1}{15}} \sum_{i < j}^6 [(0s)^4(0p)_{ij}^2].$$

Their linear combination could form a configuration which orthogonal to ψ_1 and the excited wave function of the center of mass motion (CM), as long as $b_1 = b_2$. Then, the supplemented configuration can be taken as

$$\psi_2 = \left[\left(\sqrt{\frac{5}{6}} (0s)^5(1s)[6]_{\text{orb}} + \sqrt{\frac{1}{6}} (0s)^4(0p)^2[6]_{\text{orb}} \right) [111111]_{\text{SIC}} \right]_{(IS)=(03)}, \quad (7)$$

where the size parameter b_2 is chosen as a variational parameter (later, b_1 can be varied as well for getting an even more stable solution).

Finally, the trial wave function can be expressed as

$$\Psi_{6q} = c_1 \psi_1 + c_2 \psi_2, \quad (8)$$

where c_1 and c_2 are the mixing coefficients. It should particularly be emphasized that the ψ_1 and ψ_2 are not orthogonal in general, except $b_2 = b_1$.

III. RESULTS AND DISCUSSIONS

As mentioned in the previous section, because ψ_2 is employed to complement ψ_1 , ψ_2 with a $2\hbar\omega$ excitation can be regarded as an inner structural deformation of the concerned six-quark system. Generally, the size of ψ_2 should be larger than ψ_1 's, namely $b_2 > b_1$, is required. The eigenvalue problem of the SCC of the six-quark system with given values of b_1 and b_2 should be considered first. Due to nonorthogonality of ψ_1 and ψ_2 , a generalized eigenvalue equation, secular equation,

$$\sum_{j=1}^2 \langle \psi_i | H | \psi_j \rangle c_j = E \sum_{j=1}^2 \langle \psi_i | \psi_j \rangle c_j \quad (i = 1, 2) \quad (9)$$

should be solved with certain values of b_1 and b_2 , for instance $b_1 = 0.5$ fm, as in the TCC calculation, and a value greater than 0.5 fm for b_2 . Changing value of b_2 , the obtained eigenvalue becomes a function of b_2 . The actual value of b_2 should be achieved by the variational procedure, so that the system would have minimum mass. To ensure the system being even more stable, b_1 should further be regarded as a changeable parameter, namely a two-parameter variation

$$\frac{\partial \langle \Psi_{6q} | H | \Psi_{6q} \rangle}{\partial b_i} = 0, \quad (i = 1, 2) \quad (10)$$

should be performed. Now, the obtained mass of d^* depends on the size parameters b_1 and b_2 . We plot such a dependence in Fig. 2.

From this figure, one sees that there do exist a stable point with respect to b_1 and b_2 in the $b_1 - b_2$ plane, where $b_1 = 0.5$ fm, $b_2 = 0.61$ fm, and the mass of the system reaches its minimum value of 2356 MeV. One also finds that although we vary b_1 and b_2 simultaneously, the outcome value for b_1 is very close to its starting value which has been used in the determination of model parameters. Then, the expectation value of H (includes

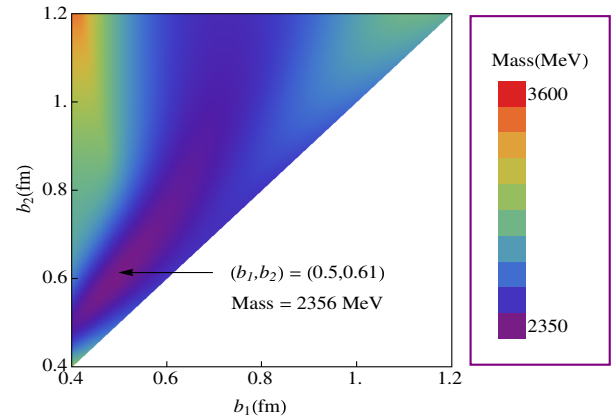


FIG. 2. The b_1 and b_2 dependence of the $d^*(2380)$ mass.

the mass term, the kinetic energy terms, and the potential terms) for ψ_1 with $b_1 = 0.5$ fm, is about 2892 MeV which is meaningful, and the overlap between $\psi_1(b_1 = 0.5$ fm) and $\psi_2(b_2 = 0.61$ fm) is about 0.201. It also reflects the reliability of the result.

For comparison, we also calculate the mass of the system with $b_1 = 0.5$ fm when the chiral field induced interaction V_{ij}^{ch} is absent. In this case, the model parameters g_u , a_{uu}^c and a_{uu}^{c0} should be adjusted to $g_u^2 = 0.878$, $a_{uu}^c = 181.7$ MeV/fm and $a_{uu}^{c0} = -178.3$ fm, so that the masses of the nucleon and Δ can be reproduced. Then, by varying b_2 , we obtain a stable mass of about 2481 MeV at $b_2 = 0.59$ fm. By comparing these two masses, we find that the chiral field induced potentials, which describe the effect of NPQCD in the medium-range, indeed provide a sizable attraction. By looking at the matrix elements of various pieces of potentials, one sees that the dominant attraction comes from the potentials induced by the σ meson exchange, one gluon exchange and linear confinement, while the effects of other interactions are relatively small or canceled with each other. When the potentials induced by the meson exchanges are absent, the net attraction becomes so weak that no stable state below the $\Delta\Delta$ threshold can be formed even the strength of the one gluon exchange potential could be increased. As a consequence, the single cluster six-quark system with the orbital [6] symmetry is indeed bound with respect to the threshold of $\Delta\Delta$, and the mass of system is close to the experimental data, which is contradict the conclusion in Ref. [20] where the important medium-range interaction due to the chiral symmetry consideration is missing. This also means that such a system is likely a hexaquark dominated state.

Moreover, we obtain the wave function of this stable state with its coefficients c_1 and c_2 being 0.849 and -0.727 , respectively. Using this wave function, we in principle can estimate the decay width of the obtained state d^* . However, the obtained width is too small to explain the data. This is because that the hypothetical trial wave function Ψ_{6q} could not well approach to the reality of the observed structure due to an improper cut in adopting inner structural deformation wave functions. Actually, we find that the wave functions with a size parameter of 0.5–1.1 fm are the most important pieces which would provide the major contribution to the width. However, in order to use a simplest possible model to describe the binding behavior of the system without losing major character, the pieces describing the information of the inner structural deformation with larger size parameters are absent in our hypothetical trial wave function, namely the adopted harmonic oscillator form of the single cluster trial wave function cannot properly describe the real behavior of the system at surface region. A sophisticated study should be carried out further. Nevertheless, our model with a rather simple but meaningful six quark structure, a basic ground state

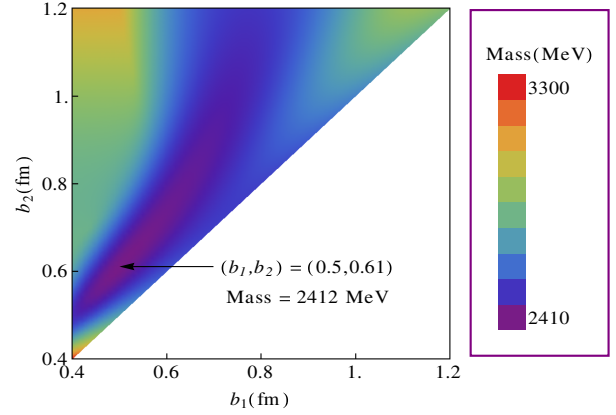


FIG. 3. The b_1 and b_2 dependence of the $IS = 30$ state.

component with the spatial [6] symmetry plus an inner structural deformation component with a $2\hbar\omega$ excitation which is also in the spatial [6] symmetry, still gives the main characters of d^* , in this case, its mass is about 46 MeV higher than the $\Delta N\pi$ threshold but about 108 MeV lower than the $\Delta\Delta$ threshold, although its mass is about 24 MeV smaller than the observed value, and its width is much smaller than the width of two Δ 's width of about 230 MeV.

It should be noted that the $2\hbar\omega$ excited state may have another symmetry structure, i.e., a wave function with a spatial [42] symmetry. However, because the wave functions with spatial [6] and [42] symmetries are orthogonal to each other, and the central force reserves the spatial symmetry [6], inclusion of the [42] symmetry wave function will not affect final result. Therefore, we disregard such a configuration in this preliminary calculation. We also limit our discussion on the states with excited energy higher than $2\hbar\omega$, due to their larger kinetic energies, and consequently, less influence on the mass of $d^*(2380)$.

The mirror state of d^* whose quantum numbers are $IS = 30$ is calculated with the same trial wave function as well. We plot the mass dependence on b_1 and b_2 in Fig. 3. The stable point occurs at $b_1 = 0.5$ fm and $b_2 = 0.61$ fm with a mass of 2412 MeV, which is around the $\Delta\Delta$ threshold.

IV. SUMMARY

In this paper, the intrinsic binding behavior of the experimentally observed $d^*(2380)$ are studied in the SCC approximation within the chiral SU(3) constituent quark model. For simplicity but keeping major character, the trial wave function is chosen as a combination of a basic ground state component with the spatial [6] symmetry and an inner structural deformation component with a $2\hbar\omega$ excitation which is also in the spatial [6] symmetry. A two-parameter variational calculation is performed in order to reach a stable state where the mass of the system has a minimum value. It is shown that there do exist a stable point, the corresponding b_1 and b_2 are 0.5 fm and 0.61 fm,

respectively, and the energy is about 2356 MeV, which is qualitatively consistent with the observed value. This result contradicts that in Ref. [20] where the interaction between quarks involves OGE and confinement potentials only. This is because that in the QCD inspired constituent quark model, the mass of the constituent quark comes from the restoration of the chiral symmetry, thus the chiral symmetry must be considered. As a practical way, the chiral field induced potential which describes the medium-range NPQCD effect should be introduced into the constituent quark model. That is why with our chiral SU(3) constituent quark model, a much lower mass of the six-quark system can be obtained. Moreover, although the estimated decay width of the system does not contradict the data, it is too small to match the observed value, because the hypothetical trial wave function is too simple to describe inner structural deformation of the system especially in the surface region where the contribution from the tail of the wave function of the system dominates the width. In a word, the binding behavior of a single cluster six-quark system with $(IS) = (03)$ is compatible with the result from the RGM

calculation qualitatively. This means that the hexaquark dominated picture may be a promising picture for d^* . For completion, the mirror state of d^* is also studied. The mass of this state is about 2412 MeV which is around the $\Delta\Delta$ threshold.

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