Possible $S-$wave dibaryons in SU(3) chiral quark model *

P.N.Shen[a,b], Q.B.Li[a], Z.Y.Zhang[a] and Y.W.Yu[a]

[a]Institute of High Energy Physics, CAS, P.O.Box 918(4), Beijing 100039, China

[b]CCAST (World Laboratory), P.O.Box 8370, Beijing 100080, China

In the framework of the SU(3) chiral quark model, the $S-$wave baryon-baryon bound states are investigated. It is found that according to the symmetry character of the system and the contributions from chiral fields, there are three types of bound states. The states of the first type, such as $[\Omega\Omega]_{(0,0)}$ and $[\Xi^*\Omega]_{(0,1/2)}$ are deeply bound dibaryon with narrow widths. The second type states, $[\Sigma^*\Delta]_{(0,5/2)}$, $[\Delta\Delta]_{(3,0)}$ are also bound states, but with broad widths. $[\Xi\Omega-\Xi^*\Omega]_{(1,1/2)}$, $[\Xi\Xi]_{(0,1)}$, and $[N\Omega]_{(2,1/2)}$ are third type states. They, like d, are weakly bound only if the chiral fields can provide attraction between baryons.

1. INTRODUCTION

In recent years, there is quite a bit activity on searching dibaryons both theoretically and experimentally. Because it is commonly believed that the radius of the dibaryon is less than $0.85fm$, studying dibaryon would enhance our knowledge about the short-range behavior of the Quantum Chromodynamics (QCD), provide the information about the nonperturbative QCD (NPQCD) and its appropriate treatment. Moreover, the existence of dibaryon is a direct evidence of quarks in hadrons and hadronic systems.

Since Jaffe predicted H [1], there have been lots of efforts devoted to the dibaryon study. The most intensive studied dibaryons are H, D^* and d'. Up to now, the most believed value of H is around The $\Lambda\Lambda$ threshold [3,4], which agrees with the experimental finding, the lower limit of $2220MeV$ [2]. The theoretical prediction for d^* varies model by model, but most believed value is several tens of MeV [5,6]. The theoretical result of d' is still away from the expected value extracted from double-charge-exchange reactions [7]. Therefore, it is reasonable to propose studies on the systems with multi-strangeness. With this idea, $\Omega\Omega(S=0,T=0)$ and $\Xi^*\Omega(S=0,T=1/2)$ were studied [8,9]. In this talk, we would demonstrate a systematic study of the possible $S-$wave dibaryons.

2. MODEL FOR STUDYING DIBARYON

Because NPQCD still cannot directly be solved, one has to use model to approximately treat the NPQCD effect. In order to reliably study dibaryon, the employed model should at least satisfy two-fold requirements: (1) The ground state properties of baryons, and the available experimental data of the nucleon-nucleon and the nucleon-hyperon scattering can

*This work is supported in part by the National Natural Science Foundation of China (NSFC) and the Chinese Academy Of Sciences.

reasonably be reproduced in the dynamical calculation. (2) In the extended application, no additional parameters are required. The SU(3) chiral quark model is just one of the models which meets the requirements [10]. The details of the model can be found in ref.[10].

The model parameters are fixed before the calculation [10]. The set of values used in ref.[10]is called Model I (Set I). In order to further reduce the number of free parameters, we choose the masses of strange scalar mesons, κ and ϵ, to be the values of the mesons with the same quantum numbers in the particle data table. Moreover, in order to test the effects of various chiral fields, we also establish the extended SU(2)chiral quark model (Model II), where σ', κ and ϵ are disregarded, and the SU(2) chiral quark model (Model III), where only π and σ are presented.

The bound state problem of the six-quark system is solved by using the Resonating Group Method (RGM). In RGM, the trial wave function of the system can be written as

$$\Psi = \mathcal{A}[\hat{\phi}_A(\xi_1,\xi_2)\hat{\phi}_B(\xi_4,\xi_5)\chi_{rel}(\vec{R})\chi_{CM}(\vec{R}_{CM})], \tag{1}$$

where $\chi_{rel}(\vec{R})$ describes the trial wave function of of relative motion between baryon clusters A and B and $\mathcal{A}$ is the antisymmetrizer. In terms of the variational method, one can solve $\chi_{rel}(\vec{R})$ and consequently the binding energy of the system.

3. RESULTS AND DISCUSSION

As is well known, the matrix element $\langle\mathcal{A}^{sfc}\rangle$, where the superscript sfc implies that $\mathcal{A}$ acts in the $spin-flavor-color$ space only, is an important measure of the action of the Pauli principle on the two-baryon state. It also specifies the symmetry character of the system. The symmetry character of the two-baryon system could generally be divided into three categories. In the first category, $\langle\mathcal{A}^{sfc}\rangle \sim 2$. This feature would be enormously beneficial to form a state with the $[6]_{orbit}$ symmetry. If the inter-baryon interaction further demonstrates the attractive character with certain strength, it is possible to form a smaller-sized bound state. In the second category, $\langle\mathcal{A}^{sfc}\rangle \sim 1$. Thus, the Pauli blocking effect here are very small so that two baryons are basically independent with each other. Then, if the inter-baryon meson-exchange interaction can provide large enough attraction, the system would be bound. This result may also be deduced in terms of a model in the baryon-meson degrees of freedom. The states with $\langle\mathcal{A}^{sfc}\rangle \sim 0$ belong to the third category. The Pauli blocking effect between baryons are incredibly serious so that the state with $[6]_{orbit}$ is almost a forbidden state, namely, it is very hard to form a bound state.

We present the calculated binding energies and the corresponding root-mean-square radii ($\mathcal{R}$) for the possible $S-$wave states in the first and second categories in Tables 1(a) and (b), respectively.

In order to see the effects of various chiral fields and give a possible range of predicted bound states, we also study these states in terms of Models II and III and tabulated the result in Table 1. From Table 1(a), one finds that in the $s=-6$ and -5 cases, The systems in Model I are bounder than in Models II and III, because the strong attraction provided by σ and strange mesons κ and ϵ. If one believes that the SU(3) model is more suitable for the multi-strangeness system, $[\Omega\Omega]_{(0,0)}$ and $[\Xi^*\Omega]_{(0,1/2)}$ should be deeply bound states with narrow widths. On the other hand, in the $s=-1$ and 0 systems, Models I and II are

Table 1
(a) Binding energy E_b and corresponding $\mathcal{R}$ for the systems with $\langle \mathcal{A}^{sfc} \rangle \approx 2$.

s	System	$\langle \mathcal{A}^{sfc} \rangle$	Model I (Set I)	Model I (set II)	Model II	Model III
			E_b //$\mathcal{R}$	E_b //$\mathcal{R}$	E_b //$\mathcal{R}$	E_b //$\mathcal{R}$
0	$\Delta\Delta(S=3, T=0)$ (d^*)	2	22.2 //1.01	18.5 //1.05	64.8//0.84	62.7//0.86
	$\Delta\Delta(S=0, T=3)$	2	16.0 //1.10	13.5 //1.14	6.3//1.25	13.2//1.11
-1	$\Sigma^*\Delta(S=0, T=5/2)$	2	24.6 //0.99	19.0 //1.04	11.7//1.13	21.5//0.99
	$\Sigma^*\Delta(S=3, T=1/2)$	2	25.9 //0.95	29.3 //0.93	78.0//0.79	76.3//0.80
-5	$\Xi^*\Omega(S=0, T=1/2)$	2	92.4 //0.71	76.5 //0.72	58.8//0.75	52.1//0.76
-6	$\Omega\Omega(S=0, T=0)$	2	113.8 //0.66	98.5 //0.67	72.6//0.70	51.9//0.73

(b) Binding energy E_b and corresponding $\mathcal{R}$ for the systems with $\langle \mathcal{A}^{sfc} \rangle \approx 1$.

s	System	$\langle \mathcal{A}^{sfc} \rangle$	Model I (Set I)	Model I (set II)	Model II	Model III
			E_b //$\mathcal{R}$	E_b //$\mathcal{R}$	E_b //$\mathcal{R}$	E_b //$\mathcal{R}$
-3	$N\Omega(S=2, T=1/2)$	1	3.5 //1.18	12.7 //0.98	31.8 //0.81	49.5 //0.74
	$\Delta\Omega(S=3, T=3/2)$	1	4.4 //1.15	14.2 //0.96	34.3 //0.80	49.6 //0.74
-4	$\Xi\Xi(S=0, T=1)$	10/9	4.1 //1.17	0.4 //1.30	-0.5 //1.33	3.1 //1.18
-5	$\Xi\Omega - \Xi^*\Omega(S=1, T=1/2)$		32.9 //0.78	32.6 //0.77	29.3 //0.79	17.6 //0.86

The units for E_b and RMS are in MeV and fm, respectively. s Stands for the strangeness.

favored by the low-spin and high-spin systems, respectively. Because the color-magnetic interaction (CMI) shows repulsive and attractive features in the $S = 0$ and 3 systems, respectively, the binding energies of the $S = 3$ systems are generally higher than those of the $S = 0$ systems. Moreover, due to the strong decay modes of both composed baryons, the widths of these bound states are broad. The results in Table 1(b) shows another type of character. Because, like d, the exchange effect is almost negligible, the resultant binding energy is very sensitive to the contributions from chiral fields. It is shown that the high-strangeness system is bounder in Model I and the low-strangeness system has larger binding energy in Model III. Nevertheless, these systems are weakly bound.

Finally, to ensure the predicted bound states are reliable and stable, we also examine their model-parameter dependencies. The m_κ- and m_ϵ-dependencies are demonstrated in Table 1 by Sets I and II. It is shown that the qualitative binding behavior does not change although the binding of most systems become slightly weaker due to the overall weaker attractive feature from κ and ϵ. Moreover, the m_s- and b_u-dependencies are plotted in Fig. 1. It is shown that the binding energy always becomes smaller with increasing b_u and decreasing m_s, but the qualitative binding behavior does not change. Therefore, our predicted bound states are stable and reliable.

4. CONCLUSION

We investigate the possible $S-$wave baryon-baryon bound states with the SU(3) chiral quark model, and test the reliabilities and stabilities of Results by using different models and model parameters. It is shown that the symmetry property, characterized by the expectation value of antisymmetrizer, of the system is a major factor to affect

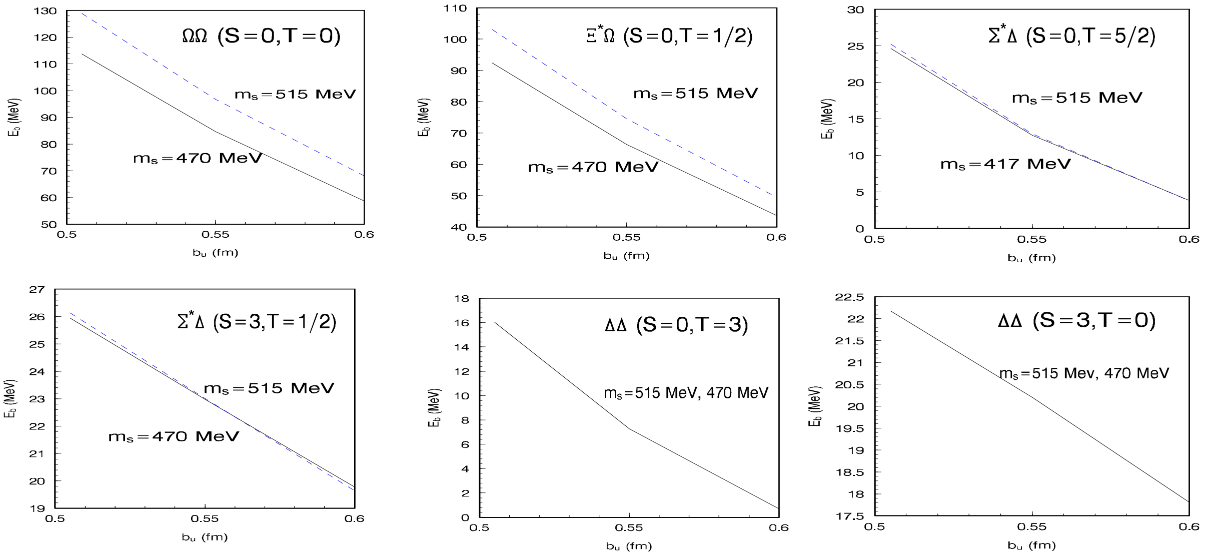

Figure 1. Binding energy change with respect to b_u and m_s.

the binding behavior. Sometimes, the contributions from various chiral fields demonstrate very important roles. We arrange all the bound states into three types. The first type states, such as $[\Omega\Omega]_{(0,0)}$ and $[\Xi^*\Omega]_{(0,1/2)}$ should be deeply bound states with narrow widths, or dibaryons.The states of second type, such as $[\Sigma^*\Delta]_{(0,5/2)}$, $[\Sigma^*\Delta]_{(3,1/2)}$, $[\Delta\Delta]_{(0,3)}$ and $[\Delta\Delta]_{(3,0)}$ (d^*) are bound states with broad widths. The states like $[\Xi\Omega - \Xi^*\Omega]_{(1,1/2)}$, $[\Xi\Xi]_{(0,1)}$, and $[N\Omega]_{(2,1/2)}$ are third types states. Like d, they generally are the weakly bound states, and their binding behaviors very much depend on the contributions from the chiral fields. We would call great attention from physicists on the states of the first and second types and wish that these states can be searched in the future experiment.

REFERENCES

1. R.L.Jaffee, Pyhs.Rev.Lett. 38 (1977) 195.
2. K.Imai, Hadrons and Nuclei with Strangeness- Proceedings of the First Sino-Japan Symposium on Strangeness Physics, Singapore, 1999, and references therein.
3. K.Yazaki, Prog.Theor.Phys. Suppl.91 (1987) 146, and references therein.
4. P.N.Shen, Z.Y.Zhang, Y.W.Yu, S.Q.Yuan, S.Yang, J.Phys. G (1999).
5. F.Wang, J.L.Ping, G.H.Wu, et al., Phys.Rev. C51 (1995) 3411.
6. X.Q.Yuan, Z.Y.Zhang, Y.W.Yu and P.N.Shen, Phys.Rev. C (1999).
7. G.Wagner, L.Ya.Glozman, A.J.Buchmann and A.Faessler,
8. Y.W.Yu, Z.Y.Zhang and X.Q.Yuan, Commun.Theor.Phys. 31 (1999) 1.
9. Q.B.Li and P.N.Shen, Chin.Phys.Lett. (1999).
10. Z.Y.Zhang, Y.W.Yu, P.N.Shen and et al., Nucl.Phys. A625 (1997) 59.