CHIN. PHYS. LETT. Vol. 28, No. 7 (2011) 071201

A Primary Study of Heavy Baryons Λ_Q, Σ_Q, Ξ_Q and Ω_Q *

ZHAO Qiao-Yan(赵巧燕)[1], ZHANG Dan(张丹)[1**], ZHANG Qiu-Yang(张秋阳)[2]

[1] *School of Physical Science and Technology, Inner Mongolia University, Hohhot 010021*

[2] *Graduate School of Zhejiang Gongshang University, Hangzhou 310018*

(Received 18 February 2011)

We perform a preliminary study of the $\frac{1}{2}^+$ and $\frac{3}{2}^+$ ground-state baryons containing a heavy quark in the framework of the chiral SU(3) quark model. By using the calculus of variations, masses of Λ_Q, Σ_Q, Ξ_Q, Ω_Q, Σ_Q^*, Ξ_Q^* and Ω_Q^*, where Q means c or b quark, are calculated. By taking reasonable model parameters, the numerical results of established heavy baryons are generally in agreement with the experimental data available, except that those of Ξ_Q are somewhat heavier. For Ω_b with undetermined experimental mass and unobserved Ξ_b^*, Ω_b^*, reasonable theoretical predictions are obtained. Interactions inside baryons are also discussed.

PACS: 12.39.−x, 14.20.Lq, 14.20.Mr DOI:10.1088/0256-307X/28/7/071201

Baryons containing heavy quarks have always been interesting. In the last decade, significant progress was made in the experimental and theoretical studies of heavy hadrons. In particular, the spectroscopy of baryons containing a singly heavy quark has obtained special attention, mainly due to recent experimental discoveries.[1] In these baryons, a heavy quark can be used as a 'flavor tag' to help us to go further in understanding the non-perturbative QCD rather than focusing on light baryons.[2] On the other hand, heavy baryons provide a laboratory to study the dynamics of light quarks in the environment of heavy quarks, such as their chiral symmetry.[3]

To date, the $\frac{1}{2}^+$ antitriplet charmed baryon states (Λ_c^+,[4] Ξ_c^+, Ξ_c^0[5]), the $\frac{1}{2}^+$ and $\frac{3}{2}^+$ sextet charmed baryon states [(Ω_c,[6] Σ_c,[7] Ξ_c',[8]) and (Ω_c^*[9] Σ_c^*,[10] Ξ_c^*[11])] have been established, while for S-wave bottom baryons, only the Λ_b,[12] Σ_b, Σ_b^*,[13] Ξ_b[14] and Ω_b[15,16] have been observed.[17] Accordingly, a large number of theoretical investigations have been carried out by various kinds of QCD-inspired models or methods to study the masses of the observed and expected heavy baryons, such as various quark models,[2,18−20] QCD sum rules,[21−23] lattice QCD,[24,25] and the bag model.[26]

The chiral SU(3) quark model is a useful non-perturbative theoretical tool for studying light hadron physics. It has been quite successful in reproducing the energies of the baryon ground states, the binding energy of the deuteron, the nucleon-nucleon (NN), hyperon-nucleon (YN), kaon-nucleon (KN) and anti-kaon-nucleon ($\bar{K}N$) scattering processes.[27,28] Valuable information has also been obtained from much work on strong interactions and multiquark clusters in this model.[29] Recently it has been extended to studying the states including heavy quarks,[30−32] and has provided interesting results. All of these successes inspire us to investigate the masses of baryons with one heavy quark following the above approaches. First, we briefly introduce the framework of the chiral SU(3) quark model, which includes the Hamiltonian and model parameters. Then the calculated masses of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ ground-state heavy baryons involving a heavy quark are shown and discussed.

The chiral SU(3) quark model has been widely described in the literature[27−32] and we recommend the reader to obtain details from those references. Here we just give the salient feature of this model. The total Hamiltonian of the heavy baryon containing one heavy quark (Qqq) can be written as

$$H = \sum_{i=1}^{3} T_i - T_G + V_{qq} + \sum V_{Qq}, \tag{1}$$

where T_i is the kinetic energy operator for a single quark, and T_G is that for the center-of-mass motion. V_{qq} represents the interaction between two light quarks (qq),

$$V_{qq} = V_{qq}^{OGE} + V_{qq}^{conf} + V_{qq}^{ch}, \tag{2}$$

where V_{qq}^{OGE} is the one-gluon-exchange (OGE) interaction, which governs the short-range perturbative QCD behavior. V_{qq}^{conf} is the confinement potential, which provides the non-perturbative QCD effect in the long distance, taken as the linear form in this work. V_{qq}^{ch} represents the chiral fields induced effective quark-quark potential, and describes the non-perturbative QCD effect of the low-momentum medium-distance range. In the chiral SU(3) quark model, it includes the scalar boson and the pseudoscalar boson exchanges,

$$V_{qq}^{ch} = \sum_{a=0}^{8} V_{\sigma_a} + \sum_{a=0}^{8} V_{\pi_a}. \tag{3}$$

Here $\sigma_0, \cdots, \sigma_8$ are the scalar nonet fields, and $\pi_0, \cdots, \pi_8$ are the pseudoscalar nonet fields. The detailed expressions of every part can be found in Refs. [27-32].

V_{Qq} in Eq. (1) is the interaction between heavy and light quark pairs (Qq),

$$V_{Qq} = V_{Qq}^{OGE} + V_{Qq}^{conf}. \tag{4}$$

*Supported by the China Postdoctoral Science Foundation Funded Project (20100471491), the Natural Science Foundation of Inner Mongolia (2010MS0101), the Inner Mongolia Educational Foundation (NJzy08006), SPH-IMU (Z20090143), and the Graduate Program of Inner Mongolia University.

**To whom correspondence should be addressed. Email: zhangdan77325@163.com

V_{Qq}^{OGE} and V_{Qq}^{conf} have the same forms as those of light quark pairs. Note that following previous work,[30−32] for Qq pairs, the Goldstone boson exchanges will not be considered in a primary study.

The model parameters for light quarks are taken from the previous work,[27] which can give a satisfactory description of the energies of the baryon ground states, the binding energy of the deuteron, the NN scattering phase shifts, and the NY cross sections. As shown in Table 1, the up (down) quark mass $m_{u(d)}$ and the strange quark mass m_s are taken to be the usual values: $m_{u(d)} = 313$ MeV and $m_s = 470$ MeV. The coupling constant for scalar and pseudoscalar chiral field coupling (g_{ch}) is determined according to the relation

$$\frac{g_{ch}^2}{4\pi} = \frac{9}{25}\frac{g_{NN\pi}^2}{4\pi}\frac{m_u^2}{M_N^2}, \tag{5}$$

with empirical value $g_{NN\pi}^2/4\pi = 13.67$. The masses of mesons are taken to be the experimental values, except for the σ meson. The m_σ is adjusted to fit the binding energy of the deuteron. The cutoff radius Λ^{-1} is taken to be the value close to the chiral symmetry breaking scale.[33] The OGE coupling constants g_u, g_s and the confinement strengths $a_{qq'}, a_{qq'}^0$ can be derived from the masses of ground state baryons.

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

m_u (MeV)	m_s (MeV)	m_σ (MeV)	g_u	g_s	g_{ch}	a_{uu} (MeV/fm)	a_{us} (MeV/fm)	a_{ss} (MeV/fm)	a_{uu}^0 (MeV)	a_{us}^0 (MeV)	a_{ss}^0 (MeV)
313	470	595	0.886	0.917	2.621	90.4	104.2	155.3	−79.6	−76.1	−87.6

Table 2. Model parameters for heavy quarks.

g_c	m_c (MeV)	a_{cu} (MeV/fm)	a_{cs} (MeV/fm)	a_{cu}^0 (MeV)	a_{cs}^0 (MeV)
0.53	1430	310.5	278.3	−186.0	−137.9
	1550	339.4	301.5	−223.5	−170.2
	1870	420.6	368.8	−324.2	−258.2
0.58	1430	276.0	240.7	−163.0	−114.3
	1550	303.0	262.7	−200.0	−146.5
	1870	376.9	325.0	−298.3	−233.3
0.60	1430	264.5	288.0	−155.0	−105.9
	1550	290.8	248.9	−191.8	−137.7
	1870	362.2	308.5	−289.2	−223.7
g_b	m_b (MeV)	a_{bu} (MeV/fm)	a_{bs} (MeV/fm)	a_{bu}^0 (MeV)	a_{bs}^0 (MeV)
0.50	4720	352.6	310.5	−190.0	−134.0
	5100	391.2	339.9	−281.0	−218.0
	5259	402.4	352.0	−316.4	−253.0
0.52	4720	338.0	292.9	−181.0	−124.0
	5100	370.3	323.9	−269.0	−209.0
	5259	390.2	332.6	−309.0	−242.5
0.60	4720	286.5	236.9	−148.0	−90.0
	5100	313.9	260.1	−234.1	−172.0
	5259	325.2	273.6	−270.0	−208.0

Table 3. Masses (MeV) of mesons with a heavy quark. Here $g_c = 0.58$, $m_c = 1550$ MeV, and $g_b = 0.52$, $m_b = 5100$ MeV. Experimental data are taken from PDG.[17]

	D	D^*	D_s	D_s^*	B	B^*	B_s	B_s^*
Experiment	1869.6	2007.0	1968.5	2112.3	5279.2	5325.1	5366.3	5415.4
Thoery	1869.8	2007.1	1968.6	2112.3	5279.3	5325.1	5366.0	5415.3

To investigate the heavy quark mass dependence, the mass of charm quark m_c is taken as several typical values 1430 MeV,[30] 1550 MeV,[34] 1870 MeV.[35] The mass of bottom quark m_b is taken as 4720 MeV,[30] 5100 MeV,[36] 5259 MeV.[35]

To test their effects on other parameters and on the spectrum, the OGE coupling constants for heavy quarks are taken as three values in an estimated range,[30] i.e. $g_c = 0.53, 0.58, 0.60$ and $g_b = 0.50, 0.52, 0.60$. The confinement strengths including a heavy quark (a_{Qq}, a_{Qq}^0) are determined by fitting the masses of heavy mesons D, D^*, D_s, D_s^* and B, B^*, B_s, B_s^*, respectively. The parameters of heavy quarks are listed in Table 2. The corresponding numerical masses of heavy mesons are exactly consistent with the experimental values. As an example, the results with $g_c = 0.58$, $m_c = 1550$ MeV and $g_b = 0.52$, $m_b = 5100$ MeV are listed in Table 3.

With all of the parameters determined, the masses of the $\frac{1}{2}^+$ lowest lying ground-state Λ_Q, Σ_Q, Ξ_Q, Ω_Q and $\frac{3}{2}^+$ S-wave Σ_Q^*, Ξ_Q^*, Ω_Q^*, where subscript Q denote c or b quark, can be calculated by the calculus of variations. The harmonic-oscillator width b_u is taken as the variational parameter. Compared with the experimental data, the numerical results can be found in Table 4, and some other theoretical predictions are illustrated as well.

From Table 4, we can see that for $J^P = \frac{1}{2}^+$, the numerical values of Λ_c are generally about 20 MeV higher than the experimental one. For Σ_c, the largest difference is 64 MeV (2518.2–2453.8 MeV), while the closest mass (2452.3 MeV) is obtained with $g_c = 0.6$ and $m_c = 1430$. The results of Ξ_c are somewhat poor, which are about 62–88 MeV higher. The results of Ω_c are at most 16 MeV far from the observed value, but the exact mass (2697.7 MeV) appears when $g_c = 0.5$ and $m_c = 1550$. Predictions of baryons with b quark are about 25 MeV heavier for Λ_b, and $76 \sim 95$ MeV higher for Ξ_b. The nearest value of Σ_b (5815.0 MeV) can be found when $g_b = 0.6$ and $m_b = 4720$, and the others are 29–55 MeV heavier. For Ω_b with uncertain experimental data, our average results are compatible with the observed value (6054.4 MeV) from Ref. [16] and the theoretical predictions from Refs. [21,24]. When $J^P = \frac{3}{2}^+$, the situation has been improved. The calculated values, which are consistent with the experimental ones, are obtained by $g_c = 0.6$ and $m_c = 1430$ for Σ_c^* (2516.6 MeV), $g_c = 0.58$ and $m_c = 1550$ for Ξ_c^* (2648.6 MeV), $g_c = 0.6$ and $m_c = 1550$ for Ω_c^* (2769.6 MeV), $g_b = 0.6$ and $m_b = 4720$ for Σ_b^* (5838.3 MeV). For unobserved Ξ_b^* and Ω_b^*, our predictions are similar to those from Ref. [19]. It is worth noting that Ref. [32] gave predictions of Λ_c ($M_{\Lambda_c} = 2269$ MeV) and Σ_c ($M_{\Sigma_c} = 2436$ MeV) using the same model as ours by taking $g_c = 0.53$ and $m_c = 1550$ MeV. While compared with our present results, their corresponding meson masses $m_D = 1883$ MeV, $m_{D^*} = 1947$ MeV move far away from the experimental values.

Table 4. Masses (MeV) of baryons with a heavy quark, accompanied by some other theoretical predictions. Experimental data are taken from PDG.[17]

g_c	m_c	Λ_c	Σ_c	Ξ_c	Ω_c	Σ_c^*	Ξ_c^*	Ω_c^*	g_b	m_b	Λ_b	Σ_b	Ξ_b	Ω_b	Σ_b^*	Ξ_b^*	Ω_b^*
0.53	1430	2307.7	2473.7	2541.9	2692.5	2536.7	2653.3	2766.7	0.50	4720	5644.2	5843.2	5879.7	6037.0	5865.6	5971.8	6083.4
	1550	2306.9	2485.5	2546.5	2697.7	2548.0	2662.5	2782.2		5100	5643.8	5858.8	5885.7	6043.6	5880.9	5984.2	6090.7
	1870	2305.9	2518.2	2559.4	2713.4	2580.1	2689.4	2799.5		5259	5643.6	5863.2	5887.5	6046.1	5885.2	5987.9	6093.8
0.58	1430	2308.8	2457.9	2535.9	2684.1	2521.5	2640.1	2767.6	0.52	4720	5644.7	5837.0	5877.2	6031.1	5859.5	5966.4	6079.6
	1550	2307.9	2468.6	2539.8	2688.5	2532.0	2648.6	2772.5		5100	5644.1	5849.8	5882.1	6039.7	5867.7	5975.1	6086.8
	1870	2306.0	2497.8	2551.2	2702.4	2560.6	2672.5	2787.9		5259	5643.9	5857.7	5885.1	6041.9	5880.0	5982.8	6088.9
0.60	1430	2309.3	2452.3	2533.8	2681.3	2516.8	2635.8	2765.0	0.60	4720	5646.2	5815.0	5868.8	6023.3	5838.3	5948.5	6068.1
	1550	2308.4	2462.6	2537.6	2685.6	2526.7	2643.9	2769.6		5100	5645.4	5858.8	5872.6	6027.4	5848.7	5956.8	6072.8
	1870	2306.5	2490.8	2548.2	2698.4	2554.2	2666.9	2783.7		5259	5645.4	5858.8	5872.6	6030.0	5852.9	5960.8	6075.8
Experiment		2286.5	2453.8	2471.0	2697.5	2518.0	2646.6	2768.3			5620.2	5807.8	5792.4		5829.0		
Ref. [19]		2297	2439	2481	2698	2518	2654	2768			5622	5805	5812	6065	5834	5963	6088
Ref. [21]		2271	2411	2432	2657	2534	2634	2790			5637	5809	5780	6036	5835	5929	6063
Ref. [22]	(GeV)	2.26	2.40	2.44	2.70	2.48	2.65	2.79			5.65	5.80	5.73	6.11	5.85	6.02	6.17
Ref. [23]	(GeV)	2.31	2.40	2.48	2.62	2.56	2.64	2.74			5.69	5.73	5.75	5.89	5.81	5.94	6.00
Ref. [24]		2290	2452	2473	2678	2538	2680	2752			5672	5847	5788	6040	5871	5959	6060
◇ 0.58	1550	2295.1	2452.8	2525.4	2672.8	2503.6	2629.8	2752.5	◇ 0.52	5100	5651.0	5806.8	5868.3	6021.1	5823.9	5933.1	6054.4

Note that J^P of baryons with * are $\frac{3}{2}^+$, and others are $\frac{1}{2}^+$. In addition, the last line with ◇ lists the masses (MeV) of heavy hadrons with $g_c = 0.58,\ m_c = 1550$ MeV, and $g_b = 0.52,\ m_b = 5100$ MeV after varying the confinement strengths.

Table 5. Masses (MeV) of heavy mesons after varying confinement strengths with $g_c = 0.58$, $m_c = 1550$ MeV, and $g_b = 0.52$, $m_b = 5100$ MeV. The units for a_{Qq} and a^0_{Qq} are the same as in Table 2.

a_{cu}	a_{cs}	a^0_{cu}	a^0_{cs}	a_{bu}	a_{bs}	a^0_{bu}	a^0_{bs}
295.3	238.7	−198.0	−136.5	247.6	164.5	−200.8	−130.0
D	D^*	D_s	D_s^*	B	B^*	B_s	B_s^*
1859.1	1993.7	1964.8	2098.1	5292.1	5325.1	5386.0	5415.3

To reduce the calculated values, we vary the confinement parameters in a reasonable range, which means that the masses of heavy mesons are roughly consistent with the experimental data. When the confinement strengths are changed, the results of Σ_Q are in good agreement with the observed ones, and the masses of Ξ_Q are reduced by $10 \sim 20$ MeV. Most of the Λ_c masses are also reduced, and the smallest one (2292.6 MeV) is only 6 MeV higher. However, little action is played for the calculation of Λ_b. In general, the numerical values are reduced less than 20 MeV for Ω_Q, 60 MeV for Σ_Q^*, 50 MeV for Ξ_Q^*, and 30 MeV for Ω_Q^*, which leads to the predictions of 10–30 MeV lower than the available observed ones. It should be noted that after changing the parameters, compared with the experimental data, the corresponding calculated masses of some heavy mesons are about 1% shifted. This relatively small difference can be acceptable in theory. As an example, with $g_c = 0.58$, $m_c = 1550$ MeV, and $g_b = 0.52$, $m_b = 5100$ MeV, the changed confinement parameters and the corresponding masses of mesons are listed in Table 5, and those of baryons are presented in the last line with ◇ in Table 4.

Table 6. The effects of meson exchanges between light quark pairs.

J^P	Baryons	Attractions	Repulsions	No effects
$\frac{1}{2}^+$	Λ_Q	π, ϵ, σ	η, η', σ'	K, κ
	Σ_Q	$\pi, \eta, \eta', \sigma', \epsilon, \sigma$		K, κ
	Ξ_Q	K, η, σ	η', κ, ϵ	π, σ'
	Ω_Q	ϵ, σ		$\pi, K, \eta, \eta', \sigma', \kappa$
$\frac{3}{2}^+$	Σ_Q^*	$\pi, \eta, \eta', \sigma', \epsilon, \sigma$		K, κ
	Ξ_Q^*	K, η', κ, σ	η, ϵ	π, σ'
	Ω_Q^*	$\eta, \eta', \epsilon, \sigma$		π, K, σ', κ

Next, let us turn to interactions in these heavy baryons. The effects of meson exchanges between light quarks are shown in Table 6, which are only related to g_{ch}, the masses and the cutoff masses of mesons. For all baryons considered here, OGE interactions are attractive, while actions of the confinement potentials depend on the confinement strengths. When we keep m_Q unchanged, with g_Q increasing, the OGE attractions will increase, too, and accordingly the confinement attractions decrease (or repulsions increase). This is obvious. Here, unchanged m_Q indicates that the total force for a heavy baryon is changeless. The attraction of OGE grows, which certainly accompanies that of confinement reducing with other conditions fixed. On the other hand, when g_Q does not change, the forces of OGE almost keep invariable. With m_Q increasing, confinement attractions will increase (or repulsions will decrease). Similarly, m_Q growing implies that the total force becomes larger for the baryon cluster, and the confinements need to be more attractive when other factors remain unchanged.

In summary, we have performed a primary study of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ ground-state baryons with one heavy quark (c or b) in the chiral SU(3) quark model. The calculated masses of established heavy baryons are generally in agreement with the available experimental data, except that those of Ξ_Q are somewhat heavier. Reasonable theoretical predictions of Ω_b with uncertain experimental mass and unobserved Ξ_b^*, Ω_b^* are presented. Meanwhile, interactions inside baryons are analyzed, too. It is suggested that our predictions could serve as a useful complementary tool for the interpretation of heavy hadron spectra. However, there are several problems in our present study deserving further discussion; for example, the effects of vector meson exchanges. Furthermore, we hope that the same approach is applied to explore more properties of heavy baryons (such as the spectra of baryons with two or three heavy quarks, or strong interactions including heavy baryons), and test the model parameters compared with the experimental data. All of these topics will be researched in future.

The authors would like to thank Professor Zhang Zong-Ye and Post-doctor Wang Wen-Ling for helpful discussions.

References

[1] For review see, e g , Rosner J L 2007 *J. Phys.* G **34** s127 and references therein
[2] Roberts W and Pervin Muslema 2008 *Int. J. Mod. Phys.* A **23** 2817 and references therein
[3] Cheng H Y 2007 ECONFC 070805 35 Cheng H Y and Chua C K 2007 *Phy. Rev.* D **75** 014006
[4] Aubert B et al [BABAR Collaboration] 2005 *Phys. Rev.* D **72** 052006
[5] Lesiak T et al [BELLE Collaboration] 2005 *Phys. Lett.* B **605** 237
[6] Aubert B et al [BABAR Collaboration] 2007 *Phys. Rev. Lett.* **99** 062001
[7] Artuso M et al [CLEO Collaboration] 2002 *Phys. Rev.* D **65** 071101
[8] Jessop C P et al [CLEO Collaboration] 1999 *Phys. Rev. Lett.* **82** 492
[9] Aubert B et al [BABAR Collaboration] 2006 *Phys. Rev. Lett.* **97** 232001
[10] Athar S B et al [CLEO Collaboration] 2005 *Phys. Rev.* D **71** 051101
[11] Aubert B et al [BABAR Collaboration] 2008 *Phys. Rev.* D **77** 012002
[12] Acosta D et al [CDF Collaboration] 2006 *Phys. Rev. Lett.* **96** 202001
[13] Aaltonen T et al [CDF Collaboration] 2007 *Phys. Rev. Lett.* **99** 202001
[14] Abazov V et al [D0 Collaboration] 2007 *Phys. Rev. Lett.* **99** 052001
Aaltonen T et al [CDF Collaboration] 2007 *Phys. Rev. Lett.* **99** 052002
[15] Abazov V et al [D0 Collaboration] 2008 *Phys. Rev. Lett.* **101** 232002
[16] Aaltonen T et al [CDF Collaboration] 2009 *Phys. Rev.* D **80** 072003
[17] For review see, e g , Nakamura K et al [Particle Data Group] 2010 *J. Phys.* G **37** 075021
[18] Capstick S and Isgur N 1986 *Phys. Rev.* D **34** 2809
[19] Ebert D, Faustov R N and Galkin V O 2005 *Phys. Rev.* D **72** 034026
Ebert D, Faustov R N and Galkin V O 2008 *Phys. Lett.* B **659** 612
[20] Valcarce A, Garcilazo H and Vijande J 2008 *Eur. Phys. J.* A **37** 217
[21] Liu X, Chen H X, Liu Y R, Atsushi H and Zhu S L 2008 *Phys. Rev.* D **77** 014031
[22] Wang Z G 2010 *Eur. Phys. J.* C **68** 459 Wang Z G 2010 *Eur. Phys. J.* C **68** 479
Wang Z G 2010 *Phys. Lett.* B **685** 59
[23] Zhang J R and Huang M Q 2008 *Phys. Rev.* D **77** 094002
Zhang J R and Huang M Q 2008 *Phys. Rev.* D **78** 094015
Zhang J R and Huang M Q 2009 *Chin. Phys.* C **33** 1385
[24] Mathur N, Lewis R and Woloshyn R M 2002 *Phys. Rev.* D **66** 014502
[25] Liu L et al 2010 *Phys. Rev.* D **81** 094505
[26] Bernotas A and Simonis V 2009 *Lithuanian J. Phys.* **49** 19
[27] Zhang Z Y, Yu Y W, Shen P N, Dai L R, Faessler A and Straub U 1997 *Nucl. Phys.* A **625** 59
[28] Huang F, Zhang Z Y and Yu Y W 2004 *Phys. Rev.* C **70** 044004
Huang F, Zhang Z Y and Yu Y W 2004 *Commun. Theor. Phys.* **42** 577
Huang F and Zhang Z Y *2004 Phys. Rev.* C **70** 064004
Huang F, Wang W L and Zhang Z Y 2008 *Int. J. Mod. Phys.* A **23** 3057
[29] Zhang D, Huang F, Zhang Z Y and Yu Y W 2005 *Nucl. Phys.* A **756** 215
Wang W L, Huang F, Zhang Z Y, Yu Y W and Liu F 2007 *J. Phys.* G **34** 1771
Wang W L, Huang F, Zhang Z Y, Yu Y W and Liu F 2007 *Eur. Phys. J.* A **32** 293
Wang W L, Huang F, Zhang Z Y, Yu Y W and Liu F 2007 *Commun. Theor. Phys.* **48** 695
Huang F, Zhang Z Y and Yu Y W 2006 *Phys. Rev.* C **73** 025207
Huang F, Zhang Z Y and Yu Y W 2005 *Phys. Rev.* C **71** 064001
Zhang D, Huang F, Dai L R, Yu Y W and Zhang Z Y 2007 *Phys. Rev.* C **75** 024001
Wang W L, Huang F, Zhang Z Y and Liu F 2008 *J. Phys.* G **35** 085003
Wang W L, Huang F, Zhang Z Y and Liu F 2010 *Mod. Phys. Lett.* A **25** 1325
[30] Zhang H X, Zhang M and Zhang Z Y 2007 *Chin. Phys. Lett.* **24** 2533
Zhang H X, Wang W L, Dai Y B and Zhang Z Y 2008 *Commun. Theor. Phys.* **49** 414
Zhang M, Zhang H X and Zhang Z Y 2007 *Commun. Theor. Phys.* **50** 437
[31] Liu Y R and Zhang Z Y 2009 *Phys. Rev.* C **79** 035206
Liu Y R and Zhang Z Y 2009 *Phys. Rev.* C **80** 015208
[32] Wang W L, Huang F, Zhang Z Y and Zou B S arXiv:1101.0453[nucl-th]
[33] Obukhovsky I T and Kusainov A M 1990 *Phys. Lett.* B **238** 142
Kusaino A M, Neudatchin V G and Obukhovsky I T 1991 *Phys. Rev.* C **44** 2343
Buchmann A, Fernandez E and Yazaki K 1991 *Phys. Lett.* B **269** 35
Henley E M and Miller G A 1991 *Phys. Lett.* B **251** 453
[34] Vijande J, Garcilazo H, Valcarce A and Fernandez F 2004 *Phys. Rev.* D **70** 054022
[35] Silvestre-Brac B and Semay C 1993 *Z. Phys.* C **57** 273
[36] Vijande J, Fernandez F and Valcarce A 2005 *J. Phys.* G **31** 481