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Σ-admixture in neutron-rich Li Λ hypernuclei in a microscopic shell-model calculation

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Abstract. We systematically investigate the structures of the Λ hypernuclei ${}_{\Lambda}$Li with the mass number $A = 7$–10 in shell-model calculations considering the ΛN-ΣN coupling in the first-order perturbation method. We find that the calculated Σ-mixing probabilities and energy shifts due to the ΛN-ΣN coupling increase with the neutron number. The Fermi-type and Gamow-Teller-type couplings, which are related to the β-transition properties of the nuclear core state, coherently contribute to the energy shift in neutron-rich hypernuclei.

1 Introduction

One of the most important subjects in strangeness nuclear physics is a study of neutron-rich Λ hypernuclei [1]. It is expected that a Λ hyperon plays a glue-like role in neutron-rich nuclei, together with a strong ΛN-ΣN coupling [2,3], which might induce a Σ-mixing in nuclei. The knowledge of the behavior of hyperons in a neutron-excess environment will significantly affect our understanding of neutron stars, because adding hyperons softens the Equation of State [4]. The purpose of our study is to theoretically clarify the structure of neutron-rich Λ hypernuclei and contribution of the ΛN-ΣN coupling by a shell model, which has successfully been applied for description of the neutron-excess nuclei [5–7].

The overbinding problem in ${}^{5}_{\Lambda}$He, which is regarded as the underbinding problem in ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He, was known in the calculation of energy levels of s-shell hypernuclei [8]. The spin-spin component of the effective ΛN interaction contributes to the splitting of the 0^{+} and 1^{+} doublet states of ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He but cannot fully explain this splitting. Recently, Akaishi and his collaborators [2,3] suggested that a coherent ΛN-ΣN coupling, which is not included in effective ΛN interactions, can resolve the underbinding problem. Because the coherent ΛN-ΣN coupling is not so large in $N \approx Z$ p-shell hypernuclei [9], the Σ-mixing probabilities and the energy shifts is not significant. However, the authors [10] found first an enhancement of the Σ-mixing probabilities and the energy shifts in the neutron-rich hypernucleus ${}^{10}_{\Lambda}$Li in the shell-model calculation, where Σ-nuclear states are included in the model space by the first-order perturbation. Thus it is expected that an investigation of the ΛN-ΣN coupling in neutron-rich hypernuclei gives a new knowledge of behavior of hyperons.

Recently, Saha and his collaborators have performed the first successful measurement of a neutron-rich Λ hypernucleus ${}^{10}_{\Lambda}$Li by the double-charge exchange reaction (π^{-}, K^{+}) on a ^{10}B target at $p_{\pi} = 1.2$ GeV$/c$ [11]. The theoretical analysis of this reaction [12] suggests that a one-step process, $\pi^{-}p \to K^{+}\Sigma^{-}$ via Σ^{-} doorways due to the $\Sigma^{-}p \leftrightarrow \Lambda n$ coupling is dominant rather than two-step processes. This means the importance of the Σ-mixing in the Λ hypernuclei. More experiments for productions of neutron-rich hypernuclei by the (π^{-}, K^{+}) reactions are planned at J-PARC [13] and analyses of these reactions provide to examine precisely a wave function involving the Σ-mixing in neutron-rich Λ hypernuclei as well as mechanisms of these reactions.

In this report, we investigate the structure of ${}_{\Lambda}$Li hypernuclei with the mass number $A = 7$–10 by focusing on the Σ-mixing probabilities and the energy shifts in shell-model calculations including ΛN-ΣN coupling. Also, we discuss the ΛN-ΣN coupling strengths in neutron-rich Λ hypernuclei in terms of the β-transition properties of the nuclear core state.

2 Formalism

2.1 Shell model for Λ hypernuclei

A shell-model Hamiltonian is given as

$$H = H_{\Lambda} + H_{\Sigma} + V_{\Lambda\Sigma} + V_{\Sigma\Lambda}, \qquad (1)$$

where H_{Λ} and H_{Σ} are the Hamiltonians in the Λ and Σ configuration spaces, respectively. $V_{\Lambda\Sigma}$ and its Hermitian conjugate $V_{\Sigma\Lambda}$ denote the two-body ΛN-ΣN coupling interaction, $\Lambda N \leftrightarrow \Sigma N$. We treat the ΛN-ΣN coupling interactions, $V_{\Lambda\Sigma}$ and $V_{\Sigma\Lambda}$, as perturbation because a Σ hyperon has a larger mass than a Λ hyperon by 80 MeV. When taking into account up to the first-order terms, we obtain the

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ν-th eigenstate with the isospin T and the angular momentum J of the Hamiltonian H as

$$|({}^{A}_{\Lambda}Z)\nu TJ\rangle = \sum_{\mu} C_{\nu,\mu}|\psi^{\Lambda}_{\mu};TJ\rangle + \sum_{\mu'} D_{\nu,\mu'}|\psi^{\Sigma}_{\mu'};TJ\rangle, \quad (2)$$

where the Λ-nuclear and Σ-nuclear eigenstates, $|\psi^{\Lambda}_{\mu};TJ\rangle$ and $|\psi^{\Sigma}_{\mu'};TJ\rangle$, are obtained by solving the eigenvalue equations,

$$H_{\Lambda}|\psi^{\Lambda}_{\mu};TJ\rangle = E^{\Lambda}_{\mu}|\psi^{\Lambda}_{\mu};TJ\rangle, \quad (3)$$

$$H_{\Sigma}|\psi^{\Sigma}_{\mu'};TJ\rangle = E^{\Sigma}_{\mu'}|\psi^{\Sigma}_{\mu'};TJ\rangle, \quad (4)$$

respectively, and the coefficients are given by

$$C_{\nu,\mu} = \delta_{\nu\mu}, \quad (5)$$

$$D_{\nu,\mu'} = -\frac{\langle\psi^{\Sigma}_{\mu'}|V_{\Sigma\Lambda}|\psi^{\Lambda}_{\nu}\rangle_{TJ}}{E^{\Sigma}_{\mu'} - E^{\Lambda}_{\nu}}. \quad (6)$$

The Σ-mixing probability $P_{\Sigma;\nu}$ and the eigenenergy E_ν for the $|({}^{A}_{\Lambda}Z)\nu TJ\rangle$ eigenstate are given by

$$P_{\Sigma;\nu} = \sum_{\mu'} |D_{\nu,\mu'}|^2, \quad (7)$$

$$E_\nu = E^{\Lambda}_{\nu} - \Delta\epsilon_\nu \quad (8)$$

in the first-order perturbation, where $E^{\Lambda}_{\nu} = E^{\Lambda}_{\mu=\nu}$ is given in Eq. (4) and

$$\Delta\epsilon_\nu = \sum_{\mu'} \left(E^{\Sigma}_{\mu'} - E^{\Lambda}_{\nu}\right)|D_{\nu,\mu'}|^2 \quad (9)$$

is the energy shift by the ΛN-ΣN coupling.

2.2 Shell-model setup

In the present shell-model calculations, we construct wave functions in the following model space: Basis states are described on the isospin base. The nucleon part of the wave function consists of the inert ^{4}He core and valence nucleons in the p-shell ($0p_{3/2}$ and $0p_{1/2}$) orbits. The hyperon part consists of a hyperon (Λ or Σ) in the $0s_{1/2}$ orbit.

For the effective NN interaction, we adopt the Cohen-Kurath (8–16) 2BME [14] that is obtained by a fit to 35 energy data of A = 8–16 nuclei by using two single-particle energies and fifteen two-body matrix elements as parameters. The effective YN interaction is written as

$$V_Y = \bar{V} + \Delta \mathbf{s}_N\cdot\mathbf{s}_Y + S_+\boldsymbol{\ell}_N\cdot(\mathbf{s}_N+\mathbf{s}_Y) + S_-\boldsymbol{\ell}_N\cdot(-\mathbf{s}_N+\mathbf{s}_Y) + TS_{12}, \quad (10)$$

where $\bar{V}$, Δ, S_+, S_- and T are radial integrals [15–17]. $\mathbf{s}_N$ and $\mathbf{s}_Y$ are spin operators for nucleons and the hyperon, respectively. $\boldsymbol{\ell}_N$ is the angular momentum operator for nucleons and is proportional to the relative $\boldsymbol{\ell}$ for states with the $0s_{1/2}$ hyperon. The tensor operator S_{12} is defined by

$$S_{12} = 3\,(\hat{\mathbf{r}}\cdot\boldsymbol{\sigma}_N)\,(\hat{\mathbf{r}}\cdot\boldsymbol{\sigma}_Y) - (\boldsymbol{\sigma}_N\cdot\boldsymbol{\sigma}_Y) \quad (11)$$

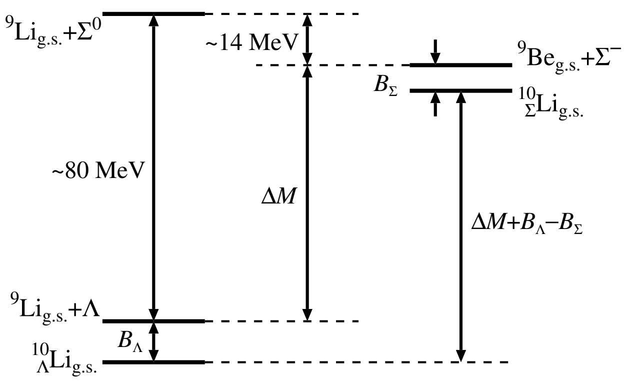

Fig. 1. Schematic energy levels for Λ-nuclear and Σ-nuclear ground states of ${}^{10}_{Y}$Li.

with $\boldsymbol{\sigma} = 2\mathbf{s}$ and $\hat{\mathbf{r}} = (\mathbf{r}_N - \mathbf{r}_Y)/|\mathbf{r}_N - \mathbf{r}_Y|$. We use the effective ΛN interaction given in Ref. [9] and the effective ΛN-ΣN and ΣN interactions [9, 18] based on the NSC97e,f potentials [19]. The values of radial integrals for these effective YN interactions are listed in Ref. [10].

3 Numerical results and discussion

3.1 Σ-mixing probabilities and energy shifts

We perform numerical calculations for the ${}_{\Lambda}$Li hypernuclei and evaluate the Σ-mixing probabilities and the energy shifts which are obtained by Eqs. (7)–(9). In Fig. 1, we show the schematic energy levels for the Λ-nuclear and Σ-nuclear ground states of ${}^{10}_{Y}$Li. Here we assume that the difference between Λ and Σ threshold energies is

$$E({}^9\mathrm{Li}_{\mathrm{g.s.}}{+}\Sigma) - E({}^9\mathrm{Li}_{\mathrm{g.s.}}{+}\Lambda) = 80\ \mathrm{MeV}, \quad (12)$$

and then the energy of the Σ-nuclear ground state $|\psi^{\Sigma}_{\mathrm{g.s.}}\rangle$ is calculated to be

$$E^{\Sigma}_{\mathrm{g.s.}} - E^{\Lambda}_{\mathrm{g.s.}} = \Delta M + B_\Lambda - B_\Sigma = 69.3\ \mathrm{MeV}, \quad (13)$$

measured from that of the Λ-nuclear ground state $|\psi^{\Lambda}_{\mathrm{g.s.}}\rangle$.

In Table 1, we show the calculated Σ-mixing probabilities and energy shifts and find that these values are the order of 0.1 % and 0.1 MeV, respectively, and increase with the neutron number (or isospin). The Σ-mixing probability is about 0.34 % and the energy shift is about 0.28 MeV

Table 1. The calculated Σ-mixing probabilities P_Σ and energy shifts $\Delta\epsilon$ for ground states of ${}_{\Lambda}$Li isotopes.

	J^{P_i}	T	P_Σ (%)	$\Delta\epsilon$ (MeV)	$\Delta\epsilon^{(a)}$ (MeV)
${}^{7}_{\Lambda}$Li	$\frac{1}{2}^+$	0	0.098	0.085	0.078
${}^{8}_{\Lambda}$Li	1^-	$\frac{1}{2}$	0.172	0.139	
${}^{9}_{\Lambda}$Li	$\frac{3}{2}^+$	1	0.211	0.172	
${}^{10}_{\Lambda}$Li	1^-	$\frac{3}{2}$	0.345	0.280	
${}^{11}_{\Lambda}$B	$\frac{5}{2}^+$	0	0.076	0.073	0.066

(a) Ref. [9]

for the neutron-rich ${}^{10}_{\Lambda}$Li ground state, which are about 3 times larger than those for ${}^{7}_{\Lambda}$Li. In order to check our shell-model calculation, we also compared our numerical results for the $Z = N$ Λ hypernuclei to Millener's work [9]. We obtain the energy shifts, e.g., $\Delta\epsilon = 0.085$ and 0.073 MeV for the ground states of ${}^{7}_{\Lambda}$Li and ${}^{11}_{\Lambda}$B, which are comparable to the Millener's results of 0.078 and 0.066 MeV, respectively. Therefore, we conclude that our calculations agree with Millener's results.

3.2 ΛN-ΣN coupling strengths

We examine an enhancement of the Σ-mixing probability and the energy shift in ${}^{10}_{\Lambda}$Li isotope by the configuration mixing in the Σ-nuclear states, which couple to the Λ-nuclear states by the ΛN-ΣN coupling. The calculated ΛN-ΣN coupling strengths $|D_{\mu'}|^2$ between the Σ-nuclear eigenstates $|\psi^{\Sigma}_{\mu'}\rangle$ and the Λ-nuclear ground state $|\psi^{\Lambda}_{\rm g.s.}\rangle$ are shown in Fig. 2. It should be noticed that a contribution of the Σ-nuclear ground state $|\psi^{\Sigma}_{\rm g.s.}\rangle$ to the Σ-mixing of the ${}^{10}_{\Lambda}$Li ground state is reduced to $|D_{\rm g.s.}|^2 = 0.002$ %, whereas the several Σ-nuclear excited states with $E^{\Sigma}_{\mu'} - E^{\Lambda}_{\rm g.s.} \approx 80$ MeV considerably contribute to the Σ-mixing. These contributions are coherently enhanced by the configuration mixing which is caused by the ΣN interaction. It is shown that the nature of the Σ-nuclear states plays an important role in the ΛN-ΣN coupling.

It is worth discussing microscopically one mechanism of ΛN-ΣN coupling in Λ hypernuclei. When a Λ-nuclear state in ${}_{\Lambda}$Li converts to a Σ^--nuclear state through the ΛN-ΣN coupling interaction, the Li core state changes into the Be core state. In other words, the β^--transition, Li → Be, occurs in the core-nuclear state. We stress that the ΛN-ΣN coupling strengths $|D_{\mu'}|^2$ are extremely sensitive to the strengths of β-transitions between the core-nuclear states. The two-body ΛN-ΣN coupling interaction $V_{\Sigma\Lambda}$ can be approximately rewritten as

$$V_{\Sigma\Lambda} \simeq V^{\rm F}_{\Sigma\Lambda} + V^{\rm GT}_{\Sigma\Lambda}, \tag{14}$$

where

$$V^{\rm F}_{\Sigma\Lambda} = \bar{V}_{\Sigma\Lambda}, \tag{15}$$

$$V^{\rm GT}_{\Sigma\Lambda} = \Delta_{\Sigma\Lambda} \mathbf{s}_N \cdot \mathbf{s}_{\Sigma\Lambda} \tag{16}$$

in the particle representation: $\bar{V}_{\Sigma\Lambda}$ and $\Delta_{\Sigma\Lambda}$ are radial integrals of central potentials. In the isospin representation, these terms can be rewritten as

$$V^{\rm F}_{\Sigma\Lambda} \propto \mathbf{t}_N \cdot \boldsymbol{\phi}_{\Sigma\Lambda}, \tag{17}$$

$$V^{\rm GT}_{\Sigma\Lambda} \propto (\boldsymbol{\sigma}_N \cdot \boldsymbol{\sigma}_{\Sigma\Lambda})\, \mathbf{t}_N \cdot \boldsymbol{\phi}_{\Sigma\Lambda}, \tag{18}$$

where $\mathbf{t}_N$ is the isospin operator for a nucleon and $\boldsymbol{\phi}_{\Sigma\Lambda}$ is the operator that changes a Λ hyperon into a Σ hyperon,

$$|j_\Sigma\rangle = \boldsymbol{\phi}_{\Sigma\Lambda}|j_\Lambda\rangle. \tag{19}$$

Because $\mathbf{t}_N$ and $\boldsymbol{\sigma}_N\mathbf{t}_N$ denote the Fermi and Gamow-Teller β-transition operators for a nucleon, respectively, $V^{\rm F}_{\Sigma\Lambda}$ and $V^{\rm GT}_{\Sigma\Lambda}$ are regarded as the Fermi-type and Gamow-Teller-type coupling interactions. The calculated strength distributions of these couplings,

$$|D^{\rm F}_{\mu'}|^2 = \left| \frac{\langle \psi^{\Lambda}_{\rm g.s.}; TJ | V^{\rm F}_{\Sigma\Lambda} | \psi^{\Sigma}_{\mu'}; TJ \rangle}{E^{\Sigma}_{\mu'} - E^{\Lambda}_{\rm g.s.}} \right|^2, \tag{20}$$

$$|D^{\rm GT}_{\mu'}|^2 = \left| \frac{\langle \psi^{\Lambda}_{\rm g.s.}; TJ | V^{\rm GT}_{\Sigma\Lambda} | \psi^{\Sigma}_{\mu'}; TJ \rangle}{E^{\Sigma}_{\mu'} - E^{\Lambda}_{\rm g.s.}} \right|^2, \tag{21}$$

are shown in Figs. 3 (a) and (b), respectively. Comparing them with Fig. 2, we see the Fermi and Gamow-Teller components coherently contribute to the ΛN-ΣN coupling strengths in the energy region of $E^{\Sigma}_{\mu'} - E^{\Lambda}_{\rm g.s.} \approx 80$ MeV. The calculated Σ-mixing probability involving both couplings is

$$\sum_{\mu'} \left| \frac{\langle \psi^{\Lambda}_{\rm g.s.}; TJ | (V^{\rm F}_{\Sigma\Lambda} + V^{\rm GT}_{\Sigma\Lambda}) | \psi^{\Sigma}_{\mu'}; TJ \rangle}{E^{\Sigma}_{\mu'} - E^{\Lambda}_{\rm g.s.}} \right|^2 = 0.350 \text{ %}, \tag{22}$$

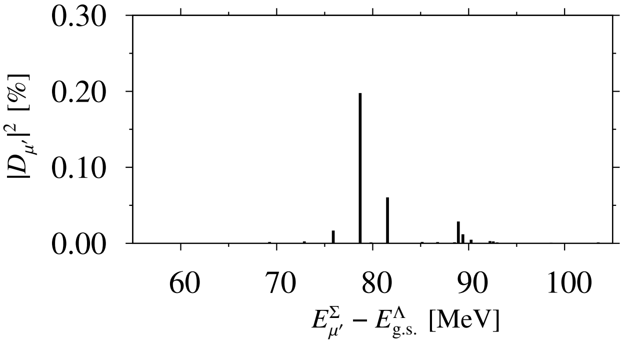

Fig. 2. ΛN-ΣN coupling strengths $|D_{\mu'}|^2$ of the Σ-nuclear eigenstates in the ground state of ${}^{10}_{\Lambda}$Li.

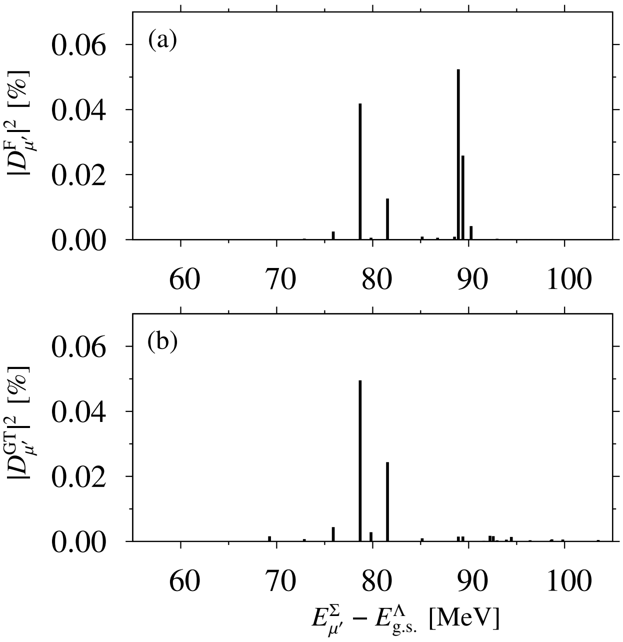

Fig. 3. (a) Fermi-type coupling strengths $|D^{\rm F}_{\mu'}|^2$ and (b) Gamow-Teller-type coupling strengths $|D^{\rm GT}_{\mu'}|^2$ of the Σ-nuclear eigenstates in the ground state of ${}^{10}_{\Lambda}$Li.

which is close to the full calculated probability $P_{\Sigma} = 0.345$ %, while $\sum_{\mu'} |D^{\mathrm{F}}_{\mu'}|^2 = 0.144$ % is obtained for the Fermi type and $\sum_{\mu'} |D^{\mathrm{GT}}_{\mu'}|^2 = 0.098$ % for the Gamow-Teller type.

In order to see the potentiality of the neutron-rich nuclei clearly, we consider the reason why the energy shift in $^{10}_{\Lambda}$Li is about 3 times larger than that in $^{7}_{\Lambda}$Li. The enhancement of the Σ-mixing probabilities in neutron-rich Λ hypernuclei is mainly due to the Fermi-type coupling interaction $V^{\mathrm{F}}_{\Sigma\Lambda}$, which might correspond to the coherent ΛN-ΣN coupling suggested in Refs. [2,3]. When we assume the weak-coupling limit for the ΛN interaction and the approximation in which all the energy differences $E^{\Sigma}_{\mu'} - E^{\Lambda}_{\nu}$ between Λ-nuclear and Σ-nuclear states are replaced by a constant value $\Delta\mathcal{E}$, we can write a sum over the Fermi-type coupling strengths as

$$\sum_{\mu'} |D^{\mathrm{F}}_{\mu'}|^2 \sim \frac{1}{\Delta\mathcal{E}}\frac{4}{3}\bar{V}^2 T\,(T+1)\,. \qquad (23)$$

Thus the Fermi-type coupling strengths play an important role in the Σ-mixing probability of neutron-rich $^{10}_{\Lambda}$Li eigenstates because these states have $T = \frac{3}{2}$. On the other hand, in the case of $^{7}_{\Lambda}$Li with $T = 0$, the Fermi-type coupling strengths vanish and then the Σ-mixing probability is generated by the Gamow-Teller-type coupling strengths.

In the Gamow-Teller transitions for ordinary nuclei, the model independent formula [20]

$$\sum B(\mathrm{GT}-) - \sum B(\mathrm{GT}+) = 3\,(N-Z) \qquad (24)$$

is well known, where $B(\mathrm{GT}\mp)$ is a strength of the Gamow-Teller $\beta^{\mp}$-transition, $|^{A}Z\rangle \to |^{A}Z\pm1\rangle$. In general, $\sum B(\mathrm{GT}+)$ becomes smaller as neutron-excess grows larger, leading to $\sum B(\mathrm{GT}-) \approx 3\,(N-Z)$. Therefore, the Gamow-Teller-type coupling is very important in Λ hypernuclei with large neutron excess.

4 Summary

We have investigated the structure of the $_{\Lambda}$Li hypernuclei in shell-model calculations including ΛN-ΣN coupling in perturbation theory. We found that the Σ-mixing probabilities and the energy shifts are the order of 0.1 % and 0.1 MeV, respectively, and they increase with the neutron number (or isospin). The reasons why the Σ-mixing probabilities are enhanced are summarized as follows: (i) The Σ-nuclear excited states can be strongly coupled with the Λ-nuclear ground state with the help of the ΣN interaction. (ii) The strong ΛN-ΣN coupling is coherently enhanced by the Fermi-type and Gamow-Teller-type coupling components. (iii) The Fermi-type coupling becomes more effective in a neutron-rich environment, increasing as $T\,(T+1)$.

References

1. L. Majling, Nucl. Phys. **A585**, (1995) 211c.
2. Khin Swe Myint, T. Harada, S. Shinmura, and Y. Akaishi, Few-Body Syst. Suppl. **12**, (2000) 383.
3. Y. Akaishi, T. Harada, S. Shinmura, and Khin Swe Myint, Phys. Rev. Lett. **84**, (2000) 3539.
4. M. Baldo, G. F. Burgio, and H.-J. Schulze, Phys. Rev. C **61**, (2000) 055801.
5. O. Sorlin and M.-G. Porquet, Prog. Part. Nucl. Phys. **61**, (2008) 602, and references therein.
6. A. Umeya and K. Muto, Phys. Rev. C **69**,(2004) 024306; **74**, (2006) 034330.
7. A. Umeya, G. Kaneko, T. Haneda, and K. Muto, Phys. Rev. C **77**, (2008) 044301.
8. R. H. Dalitz, R. C. Herndon, and Y. C. Tang, Nucl. Phys. **B47**, (1972) 109.
9. D. J. Millener, Lect. Notes. Phys. **724**, (2007) 31; Nucl. Phys. **A804**, (2008) 84.
10. A. Umeya and T. Harada, Phys. Rev. C **79**, (2009) 024315.
11. P. K. Saha, T. Fukuda, W. Imoto, J. K. Ahn, S. Ajimura, K. Aoki, H. C. Bhang, H. Fujioka, H. Hotchi, J. I. Hwang, T. Itabashi, B. H. Kang, H. D. Kim, M. J. Kim, T. Kishimoto, A. Krutenkova, T. Maruta, Y. Miura, K. Miwa, T. Nagae, H. Noumi, H. Outa, T. Ohtaki, A. Sakaguchi, Y. Sato, M. Sekimoto, Y. Shimizu, H. Tamura, K. Tanida, A. Toyoda, M. Ukai, and H. J. Yim, Phys. Rev. Lett. **94**, (2005) 052502.
12. T. Harada, A. Umeya, and Y. Hirabayashi, Phys. Rev. C **79**, (2009) 014603.
13. A. Sakaguchi, S. Ajimura, H. Bhang, L. Busso, M. Endo, D. Faso, T. Fukuda, T. Kishimoto, K. Matsuda, K. Matsuoka, Y. Mizoi, O. Morra, H. Noumi, P. K. Saha, C. Samanta, Y. Shimizu, T. Takahashi, T. N. Takahashi, and K. Yoshida, arXiv:0904.0298 [nucl-ex], 2009.
14. S. Cohen and D. Kurath, Nucl. Phys. **73**, (1965) 1.
15. A. Gal, J. M. Soper, and R. H. Dalitz, Ann. Phys. (NY) **63**, (1971) 53; **72**, (1972) 445; **113**, (1978) 79.
16. R. H. Dalitz and A. Gal, Ann. Phys. (NY) **116**, (1978) 167.
17. D. J. Millener, A. Gal, C. B. Dover, and R. H. Dalitz, Phys. Rev. C **31**, (1985) 499.
18. D. J. Millener (private communication).
19. Th. A. Rijken, V. G. J. Stoks, and Y. Yamamoto, Phys. Rev. C **59**, (1999) 21.
20. K. Ikeda, S. Fujii, and J. I. Fujita, Phys. Lett. **3**, (1963) 271.