Space-Exchange Correlation Effects in ${}^{4}_{\Lambda}$H Hypernucleus.

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(Dated: September 2, 2013)

1. Introduction.

Injection of strangeness degree of freedom inside nucleus induces new symmetries and dynamics replacing older ones [1]. Study of such systems may provide useful information about baryon-baryon and three-baryon interactions. Λ-hypernuclei may clarified interesting features of ΛN and ΣN interactions in spite of scarce data of the free space scattering. Significant progress has been made on theoretical as well as on experimental frontiers of the subject. Various theoretical framework have been adopted by various schools of thoughts such as coupled two-body model, stochastic coupled channel variational approach, Skyrme-Hartree-Fock approach, deformed Hartree-Fock approach, G-matrix calculation, relativistic mean-field approach, variational Monte Carlo (VMC) method to explore the finite hypernuclear systems. We perform a variational Monte Carlo study of ${}^{4}_{\Lambda}$H hypernucleus using a realistic Hamiltonian and a fully correlated wave function (WF) including the ΛN space exchange correlation (SEC).

2. Formalism

The Λ separation energy is calculated using the following expression

$$B_\Lambda = \frac{\langle \Psi_{NC} | H_{NC} | \Psi_{NC} \rangle}{\langle \Psi_{NC} | \Psi_{NC} \rangle} - \frac{\langle \Psi | H | \Psi \rangle}{\langle \Psi | \Psi \rangle}, \quad (1)$$

where $\Psi(\Psi_{NC})$ and $H(H_{NC})$ are referred to the ground state WF and Hamiltonian of hypernucleus (isolated A-1 bound nucleons).

The non-relativistic Hamiltonian of an A-baryon hypernucleus containing A-1 nucleons and a Λ baryon is written as

$$H = H_{NC} + H_\Lambda \quad (2)$$

where H_{NC} is the nuclear core (NC) Hamiltonian and H_Λ denotes to the lambda Hamiltonian. For S=0 sector, we employed AV18, potential for two nucleon interaction and three nucleon interaction is explained by Urbana type NNN three-body potential. Details of charge symmetric ΛN and three-body ΛNN potential, which we used here is given in Ref. [3]

The variational WF for single-Λ hypernucleus may be written as given in Ref. [2]

$$\mid \Psi \rangle = \left[1 + \sum_{i<j<k}^{A-1} (U_{ijk} + U_{ijk}^{TNI}) + \sum_{i<j}^{A-1} (U_{ij\Lambda}) + \sum_{i<j} (U_{ij}^{LS}) \right] \mid \Psi_p \rangle \quad (3)$$

where $\mid \Psi_p \rangle$ is the Jastraw WF.

3. Results and Discussions.

We perform calculations for both choices of WF: with and without SEC. For spin-averaged strength $\bar{v}$, we use three different sets of v_s and v_t, with a constant spin-dependent strength v_σ as given in Table I. For each value of $\bar{v}$, we use three values of ε: 0.1, 0.2 and 0.3. We begin our study invoking SEC in WF with $\bar{v}$=6.15, ε=0.1, at a fixed value of C^P=1.75 MeV, C^S=1.5 MeV, and adjust the repulsive strength W^D to reproduce experimental binding energy: 2.22(MeV), which is the average of ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He mirror hypernuclei. Independent variational searches for parameters of the best WF with SEC and without SEC are performed. For any change in potential strengths, we tuned WF afresh every time. The binding energy (BE) of hypernucleus is found to be sensitive for both strengths of potential $\bar{v}$ and ε. The BE of hypernucleus decreases with increasing ε. Thus, W^D is setting to lower value at higher value of ε, as required to reproduce B_Λ^{exp}. As we decrease the value of $\bar{v}$

TABLE I: The ΛN strengths in units of MeV.

v_s	v_t	$\bar{v} = (v_s + 3v_t)/4$	$v_\sigma = v_s - v_t$
6.33	6.09	6.15	0.24
6.28	6.04	6.10	0.24
6.23	5.99	6.05	0.24

TABLE II: BE of $^4_\Lambda$H hypernucleus for both choices of WF i.e SEC and No SEC. Except ε, all quantities are in units of MeV.

	SEC(A)	No SEC(B)	A-B
		ε=0.1	
$\bar{v} = 6.15$	2.22(2)	1.77(2)	0.45(3)
$\bar{v} = 6.10$	2.21(2)	1.74(2)	0.47(3)
$\bar{v} = 6.05$	2.23(2)	1.56(2)	0.67(3)
		ε=0.2	
$\bar{v} = 6.15$	2.22(2)	1.72(2)	0.50(3)
$\bar{v} = 6.10$	2.21(2)	1.68(2)	0.53(3)
$\bar{v} = 6.05$	2.22(2)	1.53(2)	0.69(3)
		ε=0.3	
$\bar{v} = 6.15$	2.20(2)	1.69(2)	0.51(3)
$\bar{v} = 6.10$	2.22(2)	1.68(2)	0.54(3)
$\bar{v} = 6.05$	2.21(2)	1.49(2)	0.72(3)

from 6.15 to 6.05 with a constant interval of 0.005 MeV, considerable decrease is noticed in BE, which we also compensated through setting the value of W^D to lower values. Details of various strengths of W^D with each set of $\bar{v}$ and ε is presented in Ref. [3]. It is evident from Table II, SEC effects on B_Λ is found to be ≈ 0.5. With increment in ε , SEC effects on B_Λ is slightly increased. A detailed study on $^4_\Lambda$H is carried out with all relevant correlations and reported in Ref. [3].

When SEC is not invoked in WF, the point proton radius is found to be more than 1.80 fm. However, the point proton radius, when SEC is invoked in WF, reduced to the range 1.68 fm to 1.72 fm, due to significant reduction in the central ΛN correlation($f^c_{\Lambda N}$) at moderate and long range of r. As a results , all baryons receive an inward pull, leading to a reduction in p and Λ densities at the periphery and enhancement in the interior density profiles. Thus, $^4_\Lambda$H and its NC are found more

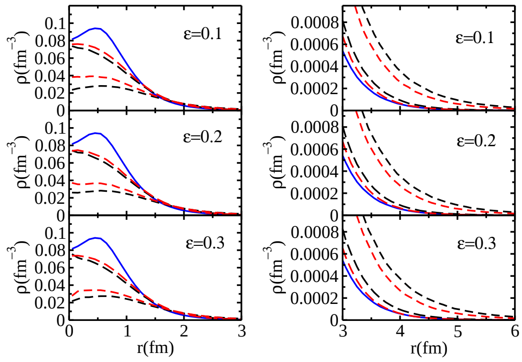

FIG. 1: One-body densities for p and Λ. Solid blue line represents p density in isolated ^{3}H nucleus. The long dashed lines with red and black colors shows p densities in NC with and without SEC respectively. The dashed lines with red and black colors shows Λ densities in NC with and without SEC respectively.

compact owing to space-exchange pressure. We may understand these results from Fig 1. We plot density profiles only for $\bar{v}$=0.3, as the features are similar for $\bar{v}$=0.2 and $\bar{v}$=0.1. Similar results are noticed in previous study of $^5_\Lambda$He and $^{\;\,6}_{\Lambda\Lambda}$He hypernuclei [2, 4].

4. Conclusion

SEC correlation significantly affects energy breakdown, Λ-separation energy, nuclear core polarization, point proton radius and density profiles. All these physical observable are found to be sensitive to $\bar{v}$ and ε, when SEC is invoked in WF. Hence a study without SEC would be misleading.

References

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