Structure of Λ-Hypernuclei with Gogny type N-N and Y-N Interactions

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Introduction

Λ-hypernuclei constitutes the simplest of strange nuclei systems (S=-1). For its theoretical description, both microscopic and phenomenological approaches have been employed [1]. In this work, we have studied the structure of Λ-hypernuclei through a phenomenological approach using self-consistent Hartree-Fock-Bogoliubov (HFB) calculations with Gogny force as an effective interactions in both $N-N$ and $\Lambda-N$ channels.

Methodology

The Hamiltonian describing the Λ-hypernuclei can be written in second quantisation as,

$$\hat{H} = \sum_{i,j} t^N_{ij}\hat{a}^\dagger_i\hat{a}_j + \sum_{i,j} t^\Lambda_{ij}\hat{c}^\dagger_i\hat{c}_j - \hat{T}_{c.m.} + \frac{1}{4}\sum_{ijkl}\bar{V}^{NN}_{ijkl}\hat{a}^\dagger_i\hat{a}^\dagger_j\hat{a}_l\hat{a}_k + \sum_{ijkl}V^{\Lambda N}_{ijkl}\hat{a}^\dagger_i\hat{c}^\dagger_j\hat{c}_l\hat{a}_k \quad (1)$$

where creation (annihilation) operators $\hat{a}^\dagger_i(\hat{a}_i)$ for nucleons and $\hat{c}^\dagger_i(\hat{c}_i)$ for the Λ hyperon respectively, t^N_{ij} and t^Λ_{ij} are the nucleon and Λ hyperon kinetic energy matrix elements respectively, $\bar{V}^{NN}_{ijkl}$ is the two body matrix element describing the anti-symmetrised $N-N$ interaction, $V^{\Lambda N}_{ijkl}$ is the two body matrix element describing the direct $\Lambda-N$ interaction and $\hat{T}_{c.m.}$ is the center of mass correction to total energy.

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We have solved the Hamiltonian given in Eq. (1) in the framework of HFB method. Here, the minimisation of the total energy of Λ hypernuclei must also include the single particle energy of Λ hyperon in addition to the Hartree-Fock and pairing energies of nucleons. For the $N-N$ interaction $\bar{V}^{NN}_{ijkl}$, the standard Gogny D1S parametrisation was used [2]. For the $\Lambda-N$ interaction $V^{\Lambda N}_{ijkl}$, we used only the central term of Gogny force without also taking into consideration the isospin dependence. That is,

$$V(\vec{r}_1,\vec{r}_2) = \sum_{i=1,2} e^{-(r_{12}/\mu_i)^2}(W_i + B_i\hat{P}_\sigma) \quad (2)$$

This is justified because of weak spin-orbit part of $\Lambda-N$ interaction and electrically neutral nature of Λ hyperon. The six unknown parameters (μ_1, μ_2, W_1, B_1, W_2 and B_2) in the Eq. (2) were determined through a χ^2 minimisation procedure called "Simulated Annealing method"(SAM) and the chosen observable for fitting is the experimental Λ single particle binding energies in various Λ-hypernuclei. The hypernuclear calculations performed in this work were done by incorporating the required modifications in *HFBaxial* code [3].

Results and discussion

We have obtained various $\Lambda-N$ Gogny parameter sets using SAM fitting protocol. In Fig. 1 we present our predicted binding energy (BE) results for $1l$ ($l = s, p, d, f$ and g) Λ states in Λ-hypernuclei with mass number A

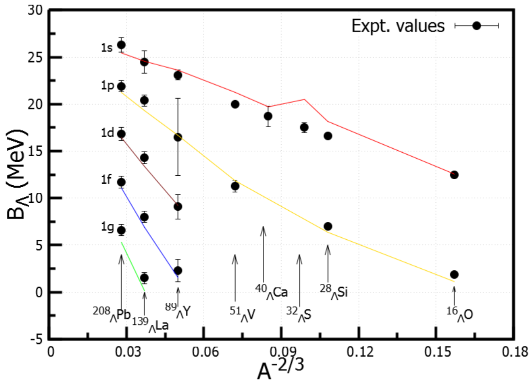

FIG. 1: Comparison of Λ single particle binding energy (B_Λ) predictions with experimental values for Λ-hypernuclei with mass number A = 16 to 208.

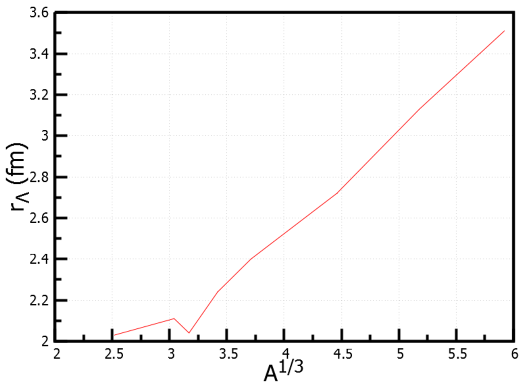

FIG. 2: Rms radii of ground state Λ orbitals (r_Λ) in Λ-hypernuclei as a function of $A^{1/3}$.

= 16 to 208 using one such obtained $\Lambda-N$ parameter set. The BE predictions with simplified $\Lambda-N$ Gogny interaction are found to be in general reasonable agreement with the experimental data. In addition, we have observed a "kink" of 1s-shell Λ BE at ${}^{32}_{\Lambda}$S for all the obtained $\Lambda - N$ parameter sets. This might be because HFB-Gogny quadrupole (β_2) potential energy surface of ${}^{32}_{\Lambda}$S has a slightly broad energy minima extending from oblate to prolate region similar to the one observed for its ordinary nuclei counterpart ^{32}S [4] and, the obtained BE result could have been improved if these fluctuations in β_2 degrees of freedom were taken into an account.

The results for root mean square (rms) radii of ground state Λ orbitals (1s-shell) are shown in Fig. 2. The values are in agreement with some hypernuclear mean field studies carried out using Skyrme forces [5]. Again, the "kink" in r_Λ was observed for ${}^{32}_{\Lambda}$S because of its correlation with the binding energy value. For the medium to heavy mass regions, r_Λ was found to be almost linearly increasing with the cubic root of the mass number $A^{1/3}$ similar to the dependence of nuclei radii on $A^{1/3}$.

Conclusions

The present work constitutes the first hypernuclear mean field studies performed using Gogny force in both $N-N$ and $\Lambda-N$ channels and the obtained BE predictions are in reasonable agreement with the experimental data. More refined calculations using density dependent term of Gogny force in $\Lambda-N$ channel and the extension of the present study to multi-strange nuclei (S=-2) will be performed in future.

Acknowledgments

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