A comparative study of spin-orbit interaction in nuclei and hypernuclei

M. Ikram[1],* Asloob A. Rather[1], M. Imran[1], and S. K. Patra[2]
[1]*Department of Physics, Aligarh Muslim University, Aligarh-202002, India. and*
[2] *Institute of Physics, Bhubaneswar-751 005, India.*

Introduction

Hypernucleus is a unique potential source of information for describing the hyperon-nucleon (YN) and hyperon-hyperon (YY) interactions and it is one of the best implication of the thought towards strangeness sector from nonstrange arena [1–3]. The Λ hyperon resides deep inside the nucleus for most of the time and as a result form a more bound system with increasing density. Presence of Λ hyperon affects the every piece of physical observables such as BE, radii, density profile, single particle energy, skin/halo etc [1, 4]. Ofcourse, the spin-orbit interaction potential is also affected due to injection of hyperon to the normal nuclei. The spin-orbit interaction potential in hypernuclei is different and remarkable weaker than nucleonic ones. There are three major contribution to the spin-orbit interaction [5]; 1)a short range component involving scalar and vector mean field potentials. 2)a "wrong-sign" spin-orbit term is generated by the pion exchange tensor forces. 3)a three body term induced by two pion exchange. In present work, our intention is to demonstrate the spin-orbit interaction potential in Λ, Σ hypernuclei with respect to their ordinary nuclei.

Formalism

The relativistic mean field (RMF) model has been remarkable successful in describing nuclei over the entire range of periodic chart including superheavy valley and also produces significant results on hypernuclei as well as multi-strange systems [1–4, 6]. For describing the hypernuclear systems, the relativistic Lagrangian is extended which is the sum of nucleonic part, single hypronic part and multi hypronic part as written by $\mathcal{L}_{total} = \mathcal{L}_N + \mathcal{L}_Y + \mathcal{L}_{YY}$ [1–4, 6]. For present calculation, we use nucleonic NL3* parameter set and hyperon-nucleon and hyperon-hyperon coupling taken from Ref. [7] to simulate YN and YY interactions.

*Electronic address: ikramamu@gmail.com

TABLE I: Binding energy and radii for considered closed shell nuclei and their Λ−, Σ−hypernuclei.

Nuclei	BE	r_n	r_p	r_t	r_{ch}	r_Λ	r_Σ
^{48}ca	414.2	3.591	3.359	3.496	3.444		
$^{48}_{\Lambda}$ca	424.8	3.558	3.354	3.460	3.439	2.829	
$^{48}_{\Lambda\Lambda}$ca	434.8	3.523	3.347	3.420	3.433	2.712	
$^{48}_{\Sigma}$ca	426.7	3.547	3.362	3.457	3.447		2.813
$^{48}_{\Sigma\Sigma}$ca	438.1	3.500	3.365	3.415	3.451		2.718
^{208}Pb	1639.3	5.736	5.448	5.624	5.499		
$^{208}_{\Lambda}$Pb	1656.7	5.719	5.441	5.604	5.492	4.062	
$^{208}_{\Lambda\Lambda}$Pb	1672.5	5.701	5.432	5.582	5.484	4.014	
$^{208}_{\Sigma}$Pb	1659.7	5.713	5.442	5.601	5.494		4.005
$^{208}_{\Sigma\Sigma}$Pb	1679.2	5.690	5.437	5.577	5.488		3.953

Results and discussion

We employed RMF model to nuclei (^{48}Ca, ^{208}Pb) and their Λ−, Σ−hypernuclei and extract the structural properties as well as spin-orbit interaction potentials which is a natural outcome of this model. Table 1 reveals that the presence of Λ and Σ hyperons increases the binding of the systems, however compact the size of the systems. Further, the spin-orbit interaction potentials for nucleonic ($V^N_{l.s}$), lambda ($V^\Lambda_{l.s}$) and sigma ($V^\Sigma_{l.s}$) are plotted in Fig. 1. This figure demonstrate that Λ and Σ spin-orbit potentials is much weaker than nucleonic ones. The value of $V^N_{l.s}$ at r=0.5 fm for ^{48}Ca comes out to be around 340 MeV. This value reaches to 400 MeV

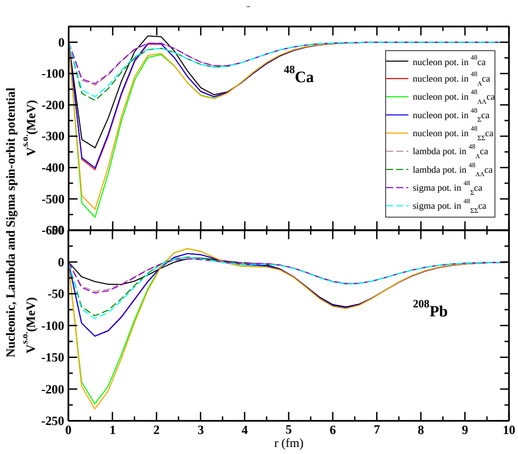

FIG. 1: Nucleonic, Lambda and Sigma spin-orbit interaction potentials for considered nuclei and hypernuclei. Solid lines represents the nucleonic potentials while lambda and sigma potentials are shown by the dashed lines.

when 1 Λ is injected to the core, 550 MeV when 2Λ is injected and the same thing happen for Σ hyperon. This results leads that the presence of Λ or Σ hyperons affects the nucleonic spin-orbit splitting to a very large extent. The one body lambda mean potentials for $^{48}_{\Lambda}$Ca, $^{48}_{\Lambda\Lambda}$Ca, and $^{208}_{\Lambda}$Pb, $^{208}_{\Lambda\Lambda}$Pb comes out to be 30±2 MeV which is in agreement with the binding of Λ particle in nuclear matter [8] as well as earlier predictions [9]. The right panel of Fig.2 shows the ratio of effective mass to bare mass of nucleons as well as lambda and sigma hyperons. More strong mean field gives rise to smaller value of ratio M*/M. The larger value of M_Λ*/M_Λ for hyperonic case is also responsible for the smaller value of spin-orbit splitting in hyperonic case. The cancellation between the short range component and the "wrong-sign" spin-orbit interaction generated by second order π-exchange with an Σ intermediate exchange would be another main reason of weaker Λ spin-orbit splitting. Present study also shows that the inclusion of hyperons also affects the $V^N_{l.s}$ to a large extent.

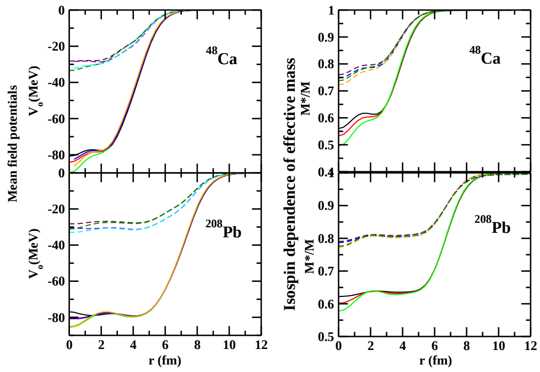

FIG. 2: Mean field potentials and isospin dependence of effective mass to bare mass for nucleons, lambda and sigma. Solid lines correspond to the nucleons while the dashed lines correspond to the hyperonic case.

References

[1] M. T. Win and K. Hagino, Phys. Rev. C **78**, 054311 (2008).
[2] M. Rufa et. al., Phys. Rev. C **42**, 2469 (1990).
[3] J. Schaffner et. al., Phys. Rev. Lett. **89**, 171101 (2002).
[4] M. Ikram et. al., Int. J. Mod. Phys. E **23**, 1450052 (2014).
[5] N. Kaiser and W. Weise, arXiv:0802.1190v1 [nucl-th] (2008).
[6] J. Mares and B. K. Jenning, Phys. Rev. C **49**, 2472 (1994).
[7] M. Chiapparini et.al., Nucl. Phys. A **826**, 178 (2009).
[8] C. B. Dover and A. Gal, Prog. Part. Nucl. Phys. **12**, 171(1984).
[9] F. Hofmann, C. M. Keil and H. Lenske, Phys. Rev. C **64**, 034314 (2001).