Spin-Orbit Interaction Potential in Nuclei and Hypernuclei

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Introduction

The microscopic understanding of the dynamical origin of the strong nuclear spin-orbit splitting is still one of the topical issues in nuclear physics and is being pursued with great vigour. The idea that nuclear spin orbit splitting is relativistic effect was taken from the spin-orbit coupling in atomic physics. This idea led to the birth of several phenomenologically successful scalar vector meson field models of nuclear structure calculations [1], wherein the nucleus is described as an ensemble of independent Dirac quasi-particles moving in the self-consistently generated scalar and vector meson fields. The motion of the nucleon on the average is non-relativistic as the typical Fermi momenta of nucleons is one third of the bare nucleon mass. However, the signatures of the relativistic nature of the nucleons manifests itself in the large spin-orbit splitting which emerges naturally in that framework and is the result of the interplay of large scalar and vector meson fields of opposite sign. The sum of these fields balances in such a way so as to produce weak central potential and their difference produces a large spin-orbit splitting in a coherent manner [2].

Theoretical Formalism

From the past several decades, the Relativistic Mean Field (RMF) theory has established itself as a promising framework and has been quite successful in describing many of the nuclear phenomena in nuclear landscape including strangeness degree of freedom [3, 4]. The relativistic Lagrangian density for singly strange hypernuclei is expresed as

$$\mathcal{L} \ = \ \mathcal{L}_N + \mathcal{L}_Y \ , \tag{1}$$

where $\mathcal{L}_N$ is the Lagrangian dendity for nucleons and $\mathcal{L}_Y$ is the Lagrangian dendity of hyperon [3, 5].

The spin-orbit interaction of baryons arises from the difference of the scalar and vector potentials. By recasting the Dirac equation into the schrödinger equivalent form, we obtain the spin-orbit potential of baryons in the following form

$$V_{ls} l.s = \frac{1}{2M_{eff}^2}\Big[\frac{1}{r}\big(g_\omega \frac{\partial V^0}{\partial r} - g_\sigma \frac{\partial \sigma}{\partial r}\big)\Big] l.s$$

where

$$M_{eff} = M - \frac{1}{2}(g_\omega V^0 + g_\sigma \sigma).$$

Proceeding along the similar lines, we obtain the lambda spin-orbit potential in the same form as in baryonic case with the coupling constants of sigma and omega mesons with nucleon being replaced by their coupling with lambda and sigma hyperons. Thus, the S.O. potential for Λ-hyperon

$$V_{ls}^{\Lambda} l.s = \frac{1}{2M_{eff}^2}\Big[\frac{1}{r}\big(g_{\omega\Lambda} \frac{\partial V^0}{\partial r} - g_{\sigma\Lambda} \frac{\partial \sigma}{\partial r}\big)\Big] l.s$$

where

$$M_{eff} = M_\Lambda - \frac{1}{2}(g_{\omega\Lambda} V^0 + g_{\sigma\Lambda} \sigma),$$

and for Σ-hyperons

$$V_{ls}^{\Sigma} l.s = \frac{1}{2M_{eff}^2}\Big[\frac{1}{r}\big(g_{\omega\Sigma} \frac{\partial V^0}{\partial r} - g_{\sigma\Sigma} \frac{\partial \sigma}{\partial r}\big)\Big] l.s$$

where

$$M_{eff} = M_\Sigma - \frac{1}{2}(g_{\omega\Sigma} V^0 + g_{\sigma\Sigma} \sigma).$$

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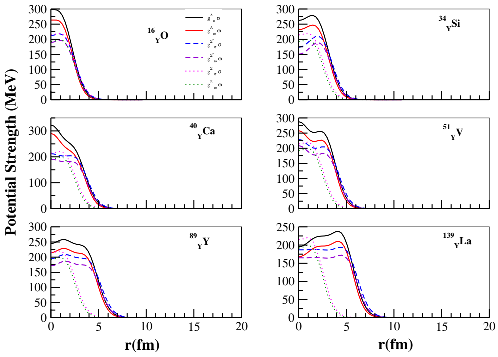

FIG. 1: Scalar and Vector potential strengths in single-Λ and single-Σ hypernuclei under study. The solid black and red lines correspond to the scalar and vector potentials of Λ. While as the blue, violet, magenta and green 4 with dashes and dotted lines for each scalar and vector potentials correspond to Σ^+ and Σ^- respectively.

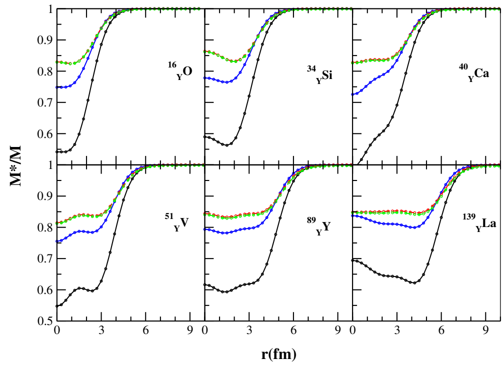

FIG. 2: Ratio of effective mass to bare mass of nucleons, lambda and sigma hyperons in hypernuclei under investigation. The solid black line corresponds to mass ratio of nucleons whereas solid blue line corresponds to Λ. The red dashed and green(dashed+dotted) lines represent the ratio of effective mass to bare mass for Σ^+ and Σ^-, respectively.

Results

RMF calculations are performed for strangeness (S) = -1 hypernuclei i.e. ${}^{16}_{Y}$O, ${}^{40}_{Y}$Ca, ${}^{89}_{Y}$Y, ${}^{34}_{Y}$Si, ${}^{51}_{Y}$V, ${}^{139}_{Y}$La (where Y = $\Lambda, \Sigma^+, \Sigma^-$). The spin-orbit interaction potential strengths are computed and scalar and vector field strengths as well as effective masses are also calculated for these hypernuclei. The coupling between the nucleons and the mesons (σ and ω) is stronger than the coupling of hyperons with these meson prpagators. As a result of this, the magnitude of scalar and vector fields is stronger in case of nucleons than hyperons as shown in Figure 1. The meson field strength for Σ-hypernuclei is weaker than nucleon as well as Λ hyperon which generate a large effective mass (Figure 2). The spin-orbit interaction is found of greater magnitude in nucleonic case than the hyperons as its magnitude is inversely proportional to effective masses which is smaller in case of nucleons as compared to hyperons as shown in Figure 3.

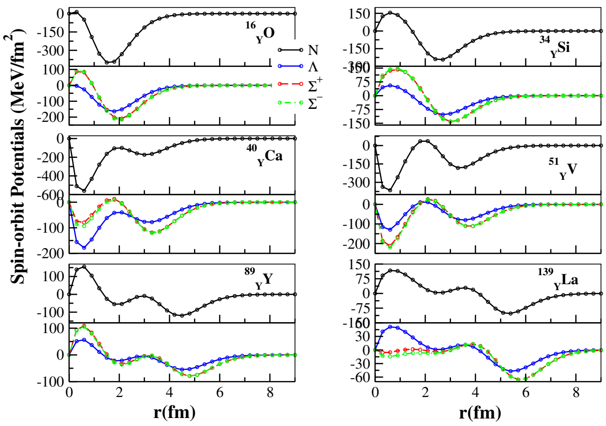

FIG. 3: Spin-Orbit interaction potentials for the single-Λ hypernuclei and single-Σ under study. The solid black line corresponds to nucleonic spin orbit potential whereas solid blue line corresponds to Λ. The red dashed line and green(dashed+dotted) line represents Σ^+ and Σ^- spin-orbit potentials respectively.

References

[1] P. Ring, Prog. Part. Nucl. Phys. 37 (1996) 193, and references therein.

[2] R. Brockmann, W. Weise, Phys. Rev. C 16 (1977) 1282.

[3] J. Schaffner, C. B. Dover, A. Gal, C. Greiner, D. J. Millener and H. Stöcker, Ann. Phys. (N.Y.) **235**, 35 (1994).

[4] N. K. Glendenning, D. Von-Eiff, M. Haft, H. Lenske and M. K. Weigel, Phys. Rev. C **48**, 889 (1993).

[5] D. Vretenar et.al., Phys. Rev. C **57**, R1060 (1998).