Spin-orbit interaction potential in Z=120 nuclei and hypernuclei

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Introduction

The microscopic understanding of the dynamical system is an important and topical issue in nuclear physics. Various relativistic and non-relativistic theoretical approaches are used by scintific or nuclear physics community to explain the nuclei over the periodic chart including superheavy region [1]. The spin-orbit either fitted or automatically generated in a model is an important interaction in order to explain the shell stucture of nuclei as well as hypernuclei. In relativistic mean-field approximation, the spin-orbit splitting originates automatically by the addition of two large scalar and vector mesons fields and thus relativistic formalism has merits over the non-relativistic approach. So, a relativistic treatment provides a valuable description of spin-orbit splitting over the conventional non-relativistic.

Hypernucleus is an unique potential probe to extend our knowledge from nucleon-nucleon interaction to lambda-nucleon interaction [2]. The spin-orbit splitting in Λ-hypernucleus is only different by only coupling constant and mass whether the fields are assumed to be same. The central and spin-orbit potential is produced by strong attractive σ scalar and repulsive ω vector potential. The typical values of attractive scalar and repulsive vector potential are -400 MeV and 350 MeV respectively. With these values the nuclear potential comes out to be -50 MeV and a huge amount of spin-orbit potential would be -750 MeV.

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Theoretical Formalism

Relativistic mean field theory is a very powerful model to extract most of the the microscopic properties of nuclei as well as hypernuclei from light system to superheavy region in nuclear landscape [2]. This model is started with lagrangian density that can be written as quantum dynamical

$$\mathcal{L} = \mathcal{L}_{\mathcal{N}} + \mathcal{L}_{\lambda},$$

where $\mathcal{L}_{\mathcal{N}}$ is the lagrangian density for nucleon and $\mathcal{L}_{\lambda}$ for Λ-hypernuclei. The spin-orbit interaction of baryons arises from the differences of scalar and vector potentials. Whereas, the nuclear mean field potential originates from the cancellation of attractive scalar S and repulsive vector V potentials.

Spin-orbit potential in nuclei:
The spin-orbit potential of nucleon-nucleon interaction is written in the following form

$$V_{ls} l.s = \frac{1}{2M_{eff}^2}\left[\frac{1}{r}\left(g_\omega \frac{\partial V_0}{\partial r} - g_\sigma \frac{\partial \sigma}{\partial r}\right)\right] l.s,$$

where M_{eff} is the effective mass written by

$$M_{eff} = M - \frac{1}{2}(g_\omega V_0 + g_\sigma \sigma_0) = M^* - \frac{1}{2}(V+S)$$

The mean and spin-orbit potentials are expressed as

$$V_{pot} = V + S, V_{ls} = \frac{M}{M_{eff}}(V - S)$$

Spin-orbit potential in hypernuclei:
The effective ΛN interaction mainly contains an attractive part produced by exchanging a scalar σ-meson and a repulsive one by exchanging a vector ω-meson. The s.o. potential

for hypernucleus can be written in the following form

$$V_{ls}^{\Lambda} l.s = \frac{1}{2M_{eff}^2}\left[\frac{1}{r}\left(g_{\omega\Lambda}\frac{\partial V_0}{\partial r} - g_{\sigma\Lambda}\frac{\partial \sigma}{\partial r}\right)\right] l.s,$$

$$M_{eff} = M_{\Lambda} - \frac{1}{2}(g_{\omega\Lambda}V_0 + g_{\sigma\Lambda}\sigma).$$

Results

In this work, we study the different kinds of potentials arise in predicted closed shell superheavy nuclei and their $\Lambda-$hypernuclei. In RMF formalsim scalar(σ), vector(ω) and isovector(ρ) meson fields are mediating quanta of NN interaction and therefore scalar, vector, isovector and coulomb potentials as represented in Fig1. The single particle mean potential is gererated by the sum of all individual potentials. Since, only the coupling constants and baryon masses is different wheather the fields are assumed to be same and thus the structure of the potentials in hypernucleus is same as the normal nucleus. The potentials in $\Lambda-$hypernucleus is weaker than conventional nucleus due to weaker strength of coupling constatnt as reflected in Fig1 and Fig2.

Spin-orbit and scalar plus vector (V+S) potentials are plotted in figure 2 for $^{292}_{\Lambda}120$, $^{304}_{\Lambda}120$ hypernuclei. The single particle mean potentials of $\Lambda-$hypernucleus comes out to be around -28MeV that is significatly equal to the Λ depth in nuclear matter. The behaviour/pattern of V_{ls}^{Λ} is almost exactly equal to the V_{ls}^{N} except its weaker strength.

TABLE I: Total, pairing, rearrangement energy and radii are given for $^{292}_{\Lambda}120$, $^{304}_{\Lambda}120$ hypernucleus. Energies are in MeV and radii are in fermi.

	BE	E_p	E_r	r_c	r_n	r_t	r_{Λ}
$^{292}120$	2061.4	9.440	934.3	6.271	6.390	6.323	-
$^{292}_{\Lambda}120$	2063.5	9.736	932.9	6.267	6.381	6.312	5.195
$^{304}120$	2138.9	10.153	965.9	6.303	6.519	6.417	-
$^{304}_{\Lambda}120$	2180.9	10.084	963.1	6.297	6.505	6.401	3.289

Structural properties such as binding energy, pairing energy, rearrangement energy and radii are listed in Table 1. It is clearly

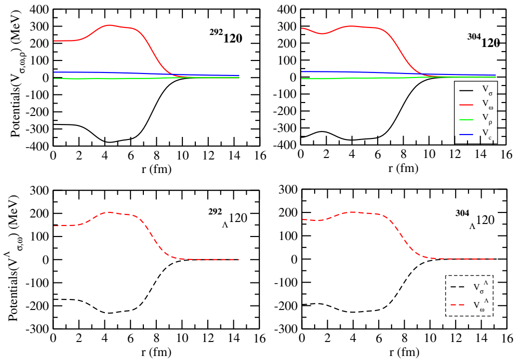

FIG. 1: Scalar, vector, isovector and coulomb po-

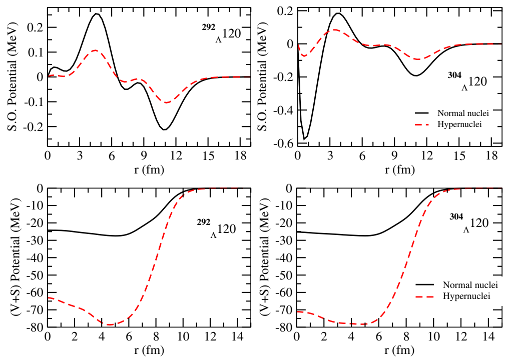

FIG. 2: S.O. interaction potentials and mean potential for $^{292}_{\Lambda}120$, $^{304}_{\Lambda}120$.

seen that the binding energy increases by injection of Λ particle whereas the size of the nucleus reduces. This is the clear indication of shrinkage effect of Λ baryon. One more thing is that the injected Λ baryon resattle the nucleons and reduces the rearrangement energy as a whole as shown in Table1.

References

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