Role of Λ hyperon in O and F drip-line nuclei

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Introduction

Hypernucleus provides an opportunity to extend our knowledge from conventional nucleon-nucleon interaction to hyperon-nucleon or in general baryon-baryon interactions [1]. Therefore, in this sense the production mechanism as well as decay modes of hypernuclei as become the subject of theoretical studies [1]. Various theoretical investigations as well as experimental attempts have been made in order to explain the states of single Λ particle coupled to the nuclear core [1]. The mean field approximation in relativistic approach has been one of the quite successful model in order of nuclear matter calculations, properties of finite nuclei throughout the periodic table and hypernuclei also [1, 2]. This model describes the nucleon and hyperon as a system of Dirac particles which interact through the exchange of virtual mesons. Owing to fully relativistic nature, the spin-orbit splitting originates naturally by the addition of two large scalar and vector mesons fields and thus relativistic formalism has merits over the non-relativistic approaches.

Exotic nuclei lie away from the stability line exhibit many interesting phenomena and that's why it is become a subject of attention by nuclear community [3]. In this work, we consider the isotopes of O and F with extremely weak binding of the outermost nucleons so-called drip-line nuclei. Without the Λ, the nucleus is unbound and further stabilized after introducing the Λ into the nuclear core. In present work, we try to explain the mechanism behind the stabilization of drip-line nucleus.

Theoretical Formalism

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

$$\mathcal{L} = \mathcal{L}_{\mathcal{N}} + L_{\Lambda},$$

where $\mathcal{L}_{\mathcal{N}}$ is the lagrangian density for nucleon and L_{Λ} 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 in nuclei and hypernuclei : 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

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

The s.o. potential for hypernucleus can be written in the following form

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

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

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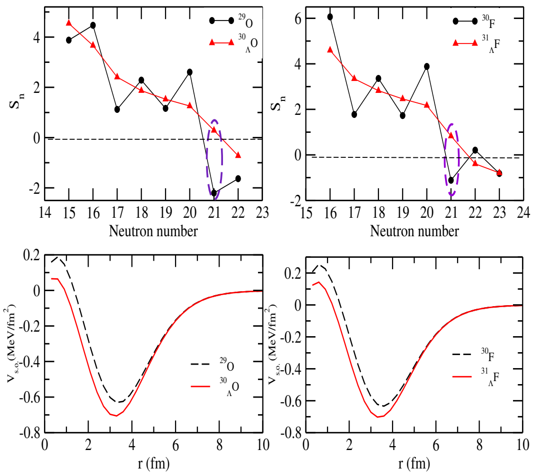

FIG. 1: One-neutron separation energy (S_n) for O and F isotopes and their hypernuclei. Spin-orbit interaction potential for ^{29}O, ^{30}F and $^{30}_{\Lambda}O$, $^{31}_{\Lambda}F$ drip-line nuclei and the hypernuclei.

Results

In this work, the role of Λ hyperon to stabilize the drip-line nuclei (for example; ^{29}O and ^{30}F) is clearly demonstrated where the systems are neutron unbound. The presence of strange baryon stabilizes the otherwise unbound nuclear core of $^{30}_{\Lambda}O$ and $^{31}_{\Lambda}F$ hypernuclei. To locate the drip-line, we estimate the one-neutron separation energy (S_n) and plot in Fig 1. From Fig.1 it is clearly visible that ^{29}O and ^{30}F with neutron number N = 21 is completely unbound with S_n = -2.206 and -1.113, respectively. The introducing strange baryon drastically change the situation completely and otherwise stabilize the nuclear core of $^{30}_{\Lambda}O$ and $^{31}_{\Lambda}F$ hypernuclei. Now, the question arises what is the mechanism behind this change? Subsequently, we make a plot of spin-orbit interaction potential in lower part of Fig 1. for drip-line nuclei and corresponding core of hypernuclei. It is clearly seen that the contribution of s.o. term in the core of hypernucleus is significantly more and therefore enhance the binding and otherwise bound the unbound nucleus. However, a

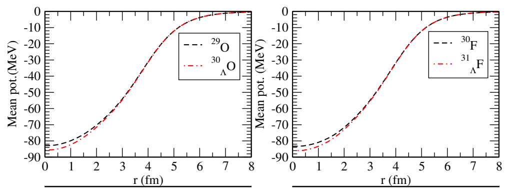

FIG. 2: Mean potential for ^{29}O, ^{30}F and $^{30}_{\Lambda}O$, $^{31}_{\Lambda}F$.

change in the central mean field potential is observed as clearly reported in Fig.2. The results conclude that the increasing strength of spin-orbit term provides the extra binding and otherwise bound the unbound nuclear core.

In summary, The relativistic mean field model with BCS pairing is applied for the description of Λ hypernuclei with neutron excess. The addition of Λ hyperon to O and F isotopes can stabilize and otherwise bound the unbound nuclear core. Thus, a significant contribution of spin-orbit term is fully responsible to stabilize the nuclear core of O and F hypernucleus.

References

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