Studies on binding energies of Λ hypernuclei

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Introduction

The investigations of possible extension of periodic table in to the region of strangeness have been performed since the first observation of hypernuclear fragment. Hypernuclei are many body systems consisting of conventional nucleons and one or more strange baryons. The first observation of hypernucleus was made by the Polish physicists Danysz and Pniewski. Several nuclear properties such as size, shape, fission barrier and density distribution etc may change when a nucleon is replaced by a hyperon.

Among various hypernuclei, Λ hypernuclei are the most known and well studied one. Various theoretical and experimental works have been carried out for studying the Λ hypernuclei in the past few decades.

In the present paper we have studied the binding energy per baryon (BE/A) of all the experimentally known hypernuclei using various theoretical methods. The comparison between the stability of the normal and hypernuclei are also performed.

Binding energy of Λ hypernuclei

Different extensions of the Bethe-Weizsäcker mass formula (BWMF) are usually used for studying the binding energies of Λ hypernuclei. In the present work we have used the following formulae for the calculation of BE/A.

- **Formula of Lévai et al. [1]**

$$B(N,Z,\Lambda) = a_v A - a_s A^{2/3} - a_c \frac{Z^2}{A^{1/3}} - a_a \frac{(N-Z)^2}{A} + a_y \frac{S}{A^{¥_y}} + a_m \frac{\langle \hat{M} \rangle}{A^{¥_m}} \quad (1)$$

Here A = N + Z + Λ and S = Y – B and $\langle \hat{M} \rangle$ represents the Majorana operator. Details of the formula can be found in Ref. [1].

- **Formula of Dover et al. [2]**

$$B = -a_v A + b_v yA + a_s^{(0)} A^{2/3} + a_c^{(0)} \frac{Z^2}{A^{1/3}} + a_x^{(0)} x^2 A + 120 A^{-2/3} ¢_{\Lambda,1} \quad (2)$$

Here $x = \frac{(N-Z)}{A}$ and $y = \frac{\frac{1}{2}(Z+N)-\Lambda}{A}$. Details of the formula can be found in Ref. [2].

- **Formula of Botvina et al. [3]**

$$B(A,Z) = 16A - 18A^{2/3} - 0.72\frac{Z^2}{A^{1/3}} - 25\frac{(A-H-2Z)^2}{(A-H)} - \frac{H}{A}\left[-10.68A + 21.27A^{2/3}\right] \quad (3)$$

Here A is the mass number, Z is the atomic number and H is the number of hyperons in the hypernuclei.

- **Formula of Samanta et al. [4]**

$$B(A,Z) = a_v A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} - a_{sym} \frac{(N-Z_c)^2}{\left[1+e^{-A/17}\right]A} + ¢_{new} + n_Y\left[0.0335(m_Y) - 26.7 - 48.7\frac{|S|}{A^{2/3}}\right] \quad (4)$$

The details of the formula can be found in Ref. [4].

Results and Discussion

We have studied the binding energies of all the 35 experimentally synthesized single Λ hypernuclei from ${}^{4}_{\Lambda}H$ to ${}^{208}_{\Lambda}Pb$, using four different methods based on BWMF. Since the experimental separation energies are available for all these 35 nuclei, the binding energies can also be found out using,

$$BE({}^{A}_{\Lambda}X)_{\exp} = BE({}^{A-1}X)_{\exp} + (S_\Lambda)_{\exp} \quad (5)$$

The binding energies of normal nuclei $BE({}^{A-1}X)_{\exp}$ are taken from the recent experimental mass table of Wang et al.

Figure 1 gives the variation of binding BE/A as function of mass number for the experimentally confirmed single Λ hypernuclei. The calculations using various methods can also be seen in figure. The variation of BE/A shows the same trend as that of normal nuclei. BE/A of lighter and heavier hypernuclei are smaller than that of medium mass hypernuclei. This indicates the stability of medium mass hypernuclei as compared to the lighter and heavier ones.

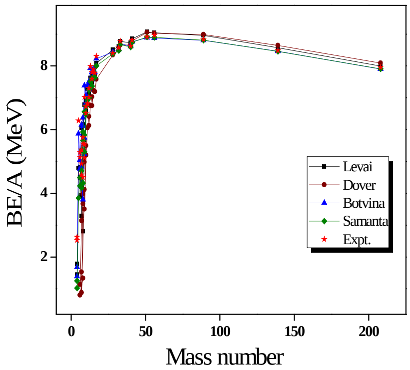

Fig. 1 The variation of binding energy per baryon as a function of mass number for the experimentally confirmed single Λ hypernuclei.

The plot of mass number versus BE/A for normal and hypernuclei are given in figure 2. The comparison shows that the variation of BE/A with respect to the mass number are the same for normal and hypernuclei. Hypernuclei are more stable than the normal nuclei with the same mass number. The variation of BE/A for hyper and normal nuclei with respect to the neutron number is shown in Figure 3. It is clear that the hypernuclei are more tightly bound than the normal nuclei with same neutron number. Using RMF theory [5], it was seen that a Λ hypernucleus will be more stable if it is made by adding a Λ hyperon to a stable normal nuclear core, or by replacing a neutron by a Λ hyperon to a stable normal nuclear core. Our study is in agreement with these predictions.

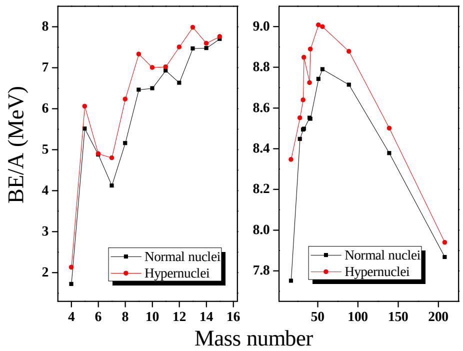

Fig. 2 The variation of binding energy per baryon as a function of mass number for the experimentally confirmed normal and single Λ hypernuclei.

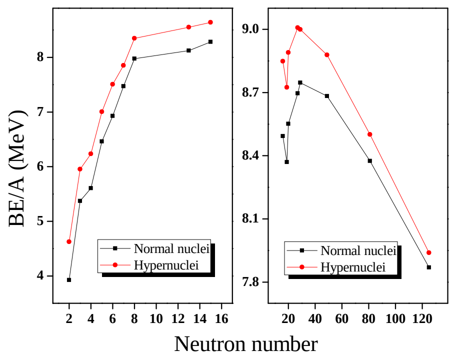

Fig. 3 The variation of binding energy per baryon as a function of neutron number for the experimentally confirmed normal and single Λ hypernuclei

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