Light mass neutron rich hypernuclei

Bipasha Bhowmick,* A. Bhattacharyya, and G. Gangopadhyay†

Introduction

The production mechanisms, spectroscopy, and decay modes of hypernuclear states have been the subject of many theoretical studies. Extensive reviews of the experimental and theoretical status of strange-particle nuclear physics can be found in[1–4]. The most studied hypernuclear system consists of a single Λ particle coupled to the nuclear core. Theoretical models used in studies of hypernuclei extend from non-relativistic approaches based on OBE models for the Λ-N interaction, to the relativistic mean field approximation and quark-meson coupling models. However, the present knowledge of the Λ-nucleus interaction, and of hypernuclear systems in general, is restricted to the valley of β stability. In view of recent advances in producing light nuclei very close to proton and neutron drip lines using radioactive ion beams, the study of ground-state properties of these nuclei has assumed importance. An extreme neutron-to-proton ratio has been achieved and is likely to be achieved in the near future. These exotic nuclei provide a testing ground of various theoretical models which must explain the systematics of various properties over long chains of isotopes. Exotic nuclei on the neutron-rich side are especially important in nuclear astrophysics. They are expected to play an important role in nucleosynthesis by neutron capture (r-processes). Knowledge of their structure and properties would help the determination of astrophysical conditions for the formation of neutron-rich stable isotopes. On the neutron- rich side, the drip line has only been reached for very light nuclei. It has been suggested [5] that a study of Λ hypernuclei with a large neutron excess could also display interesting phenomena. On one hand such hypernuclei, corresponding to core nuclei which are unbound or weakly bound, are of considerable theoretical interest. On the other hand, one could speculate on the possible role of neutron-rich Λ hypernuclei in the process of nucleosynthesis.

One expects that neutron-rich hypernuclei where a Λ hyperon lives in the neutron-excess environment, provide more exotic candidates than the ordinary neutron-rich nuclei, because the Λ hyperon acts as a nuclear glue in nuclei, as pointed out by Majling [5]. The behavior of the Λ in the neutron-excess environment is strongly connected with the nature of neutron stars and compact stars [6, 7]. The presence of hyperons in high-density nuclear medium significantly affects the maximal mass of neutron stars because it makes the Equation of State (EoS) soften. However, the baryon fraction in neutron stars is found to depend on properties of hypernuclear potentials [6, 7]. Therefore, the study of neutron-rich Λ hypernuclei is one of the most promising subjects to examine the hypernuclear potentials in the neutron-excess environment. Several experimental attempts to produce such neutron-rich Λ hypernuclei were carried out by double-charge exchange (DCX) reactions such as (stopped K^-, π^+) [8, 9] and (π^-, K^+) [10] on stable nuclear targets. Now, further experiments are planed at J-PARC facilities (J-PARC E10) [11] to investigate more exotic structures of the neutron-rich hypernuclei by which one can also get insight into halo nuclei property, ΛN-ΣN mixing, ΛNN 3-body force etc [13].

Results

In this work the relativistic mean field theory is used to study the neutron dripline of light single-Λ, double-Λ, Ξ^- hypernuclei and compare them with the corresponding normal

*Electronic address: bips.gini@gmail.com
†Department of Physics University,University of Calcutta,92 A.P.C Road,Kolkata-700009

nuclear driplines. The FSUGold lagrangian density which has been extended to include the hyperons has been used [12].

In Fig. 1 we represent the results of our calculations for the neutron driplines of the single-Λ, double-Λ and Ξ^- hypernuclei and compare them with that obtained for the normal nuclei for $N \leq 22$. We see that here for half of the cases the dripine shifts towards more neutron rich side when one or more hyperon is added to the normal core. In all the cases except for Z=5 and 15 the neutron dripline does not change due to inclusion of a single -Λ hyperon. However the inclusion of two Λs has very prominent effect on the dripline and this effect is maximum for Z=16. Whereas the effect of Ξ^- is only visible in case of Z=15 and 16. Therefore Z=15 and 16 seems to be really important if one wants to study the effects of different hypernuclei on the neutron dripline.

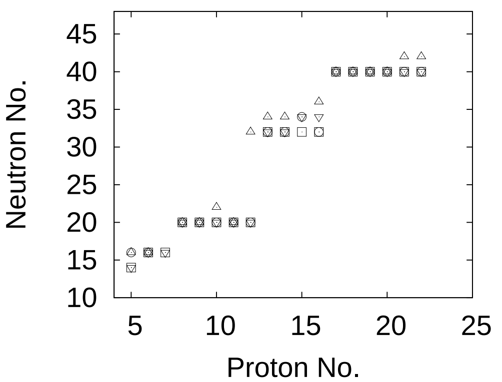

FIG. 1: Neutron dripines of single-Λ, double-Λ, Ξ^- hypernuclei as compared to that of the normal nuclei for $Z \leq 22$. Open squares present the neutron driplines of normal core nucleus, open circles present that of the single-Λ hypernuclei and open up and down triangles represent the same for ΛΛ and Ξ^- hypernuclei, respectively.

The effect of inclusion of strange baryons on the neutron dripline of a normal nuclear core is similar irrespective of whether Z is odd or even. We see the shell effects visible at the normal magic numbers Z=16,20,40 unaffected by the inclusion of hyperons.

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