Shell/Sub-Shell closure at N = 82 over the isotopic chain of Ba-nuclei within relativistic mean-field formalism

N. Biswal[1],* Praveen K. Yadav[2], Monalisa Das[1], S. Mishra[3], and R. N. Panda[1]
[1]*Department of Physics, Siksha O Anusandhan Deemed to be University, Bhubaneswar-751030, India*
[3]*School of Physics and Materials Science, Thapar Institute of Engineering and Technology, Patiala-147004, Punjab, India and*
[3]*Department of Physics, Parala Maharaja Engineering college, Berhampur-761003, India*

Introduction

In recent years, there has been increasing interest in exploring the structural evolution of exotic nuclei using experimental and theoretical frameworks. Through experimental facilities like radioactive ion beams and accelerators, more than 5000 nuclei have been synthesized around the world. These experiments allow us to expand our preexisting knowledge of the nuclear structure of finite nuclei having extreme values of isospin asymmetry and also put to the test the existing theoretical models. On the theoretical front, the non-relativistic models, including Skyrme Hartree-Fock (SHF) and Gogny, provide reasonably accurate results for $\beta-$ stable nuclei. However, moving away from the stability line, the non-relativistic description of the nuclear system starts to fail. In this regard, the relativistic mean field (RMF) theory provides a robust and efficient technique for describing several features of the many-body problem capable of investigating the nuclear system of a finite nucleus, dynamics of heavy-ion collision, and astrophysical objects, including neutron stars.

The RMF formalism has several advantages over the non-relativistic prescription, such as it accounts for the spin-orbit interactions and naturally resolves the Coester-band problem, defined as the shift in the saturation curve toward the empirical value. Moreover, it provides a successful description of nuclear matter properties throughout the nuclear landscape, extending to the super-heavy region having extreme neutron-proton asymmetry.

*Electronic address: nibeditabiswal2008@gmail.com

It is widely known that the experimental binding energy (BE) is one of the most precisely determined quantities [1]. Many of the nuclear matter properties depend upon the binding energy, such as nucleon separation energy (S_{2n}) and differential variation of nucleon separation energy (dS_{2n}), which serve as vital tools in studying the structural evolution across the isotopic and isotonic chains. In this work, we study the bulk properties of Ba ($Z = 56$) isotopic chain by using the axially deformed relativistic mean-field with BCS pairing for non-linear NL3* and Relativistic-Hartree-Bogoliubov approach with density-dependent DD-ME2 and compare the results with the FRDM predictions and available experimental data. This study predicts new shell and/or sub-shell closure for Ba- isotopic chain in the mass region of $A = 114$ to 148. The appearance of the shell and/or sub-shell from bulk properties is further confirmed by isospin-dependent properties such as symmetry energy and its components at local density (not shown here) within the coherent density fluctuation model.

Theoretical Formalism

The RMF equations are solved self-consistently by importing different inputs of initial deformation. A detailed description regarding the characteristic Lagrangian and field tensor is given in Ref. [1, 2]. Using the binding energies $BE(Z, N)$ and $BE(Z, N-2)$ and the neutron mass m_n it is possible to calculate the two neutron separation energy $S_{2n}(Z, N) = -BE(Z, N) + BE(Z, N-2) + 2m_n$. Within the coherent density fluctuation model (CDFM), the symmetry energy (S^A) is calculated as [4]

$$S^A = \int_0^\infty dx |\mathcal{F}(x)|^2 S^{NM}(x), \tag{1}$$

where $|\mathcal{F}(x)|^2$ refers to the weight function obtained after folding the symmetry energy at local density $S^{NM}(x)$. The weight function $|\mathcal{F}(x)|^2$ is given as

$$|\mathcal{F}(x)|^2 = -\left(\frac{1}{\rho_0(x)} \frac{d\rho(r)}{dr}\right)_{r=x}. \tag{2}$$

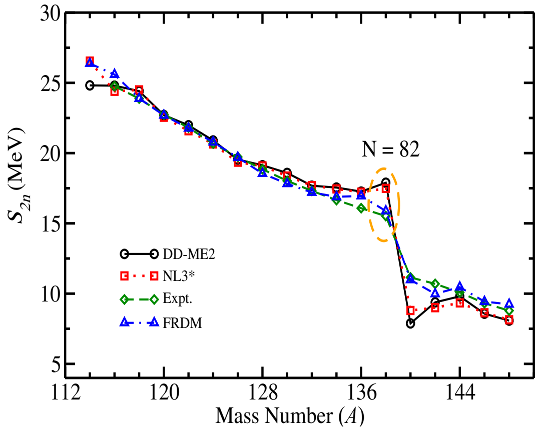

FIG. 1: The two neutron separation energy $S_{2n}(Z, N)$ as a function of mass number A for DD-ME2 and $NL3^*$ force parameters for $^{112-148}$Ba nuclei are compared with the FRDM predictions and the experimental data.

Results and discussion

Using the computed binding energy from NL3* and DD-ME2 force parameter sets for *Ba*- isotopic chain, we calculate the two neutron separation energy using the above-defined relation. The $S_{2n}(Z, N)$ provides detailed information about the Q-value corresponding to the hypothetical transfer of two neutrons from the ground state having N neutrons to that of $N - 2$.

The differences in the ground-state characteristics of both nuclei, including pairing, deformation, and neutron-to-proton asymmetry, directly contribute to the S_{2n} (Z, N). In addition, the Q-value is an important indicator in determining the possibility of spontaneous and simultaneous neutron emissions. The results of the $S_{2n}(Z, N)$ calculation is compared with the FRDM predictions and available experimental data as shown in Fig. 1. From the figure, one may easily observe the smooth decrease in the $S_{2n}(Z, N)$ energy till mass number $A = 138$, which corresponds to neutron number $N = 82$. A sharp discontinuity or kink is observed at $N = 82$. It is widely known that a small discontinuity in the nuclear matter properties signifies the possible existence of shell and/or sub-shell closure across the isotopic and isotonic chains. Here, the two neutron separation energy shows a kink when the usual trend breaks, indicating that more energy is needed to extract two neutrons from a nucleus with a magic shell configuration than its neighboring nuclei.

These preliminary findings based on bulk nuclear properties will be expanded further by including isospin properties, which include density-dependent symmetry energy and its surface and volume components using the coherent density fluctuation model [3, 4] within the RMF formalism. The detailed result of the variation of the bulk and isospin properties of *Ba*- isotopic chain will be presented at the conference and also communicated to the journal shortly.

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References

[1] M. Bhuyan, Phys. Rev. C **92**, 034323 (2015)

[2] P. Ring, Prog. Part. Nucl. Phys. **37**, 193 (1996).

[3] M. Bhuyan *et al.*, Phys. Rev. C **97**, 024322 (2018).

[4] M. K. Gaidarov *et al.*, Phys. Rev. C **84**,034316 (2011).