Ground State Bulk and Surface Properties of N=42 Isotones

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Introduction

Among the nuclear physics community, studying nuclei with large proton-neutron ratios (exotic nuclei) is one of the interesting research areas, both theoretically and experimentally. The availability of radio-active ion beam facilities and sensitive technology in terms of detection have diversified our present knowledge of nuclei near the drip line (far from the β- stability line). Primary/elementary information about the stability of the nuclear system comes from the study of ground-state bulk properties. Furthermore, the captivating concern in such types of exotic nuclear systems is the appearance of contemporary magic numbers along with the traditional magic numbers [1]. Different experiments all over the world, such as GSI(Germany), RIKEN (Japan), etc.[1], are studying the possible properties of exotic nuclei with high isospin asymmetry.

Since the symmetry energy directly connects with the isospin asymmetry of the nuclear system (finite and infinite nuclear matter), it is a crucial entity for exploring the structure of the ground state nuclei, the physics of neutron stars, and heavy ion reactions [1]. Determination of symmetry is an important step. Since its measurement is not directly possible, it can be obtained from related observables. The importance of symmetry energy and its density dependence has motivated us to study the N=42 isotonic chain.

The symmetry energy, along with the neutron pressure and symmetry energy curvature, collectively known as surface properties, have been calculated using the Coherent Density Fluctuation Model (CDFM). CDFM uses the density obtained from the relativistic mean-field model (RMF) with NL3 [2] and IOPB-I [3]. RMF provides the necessary bulk properties such as deformation, binding energy, charge radii, pairing energy, and neutron skin thickness.

Formalism

The standard form of RMF Lagrangian density can be found in Ref. [3]. The binding energy per particle can be expanded in terms of the isospin asymmetry parameter α as $BE/A = e(\rho,\alpha) = e(\rho,0)+C(\rho)\alpha^2+$ higher order terms. Further, the second term of the above equation $C(\rho)$ (nuclear matter symmetry energy) can be expanded through Taylor series expansion around saturation density ρ_0 as:

$$C(\rho) \;=\; J + L\eta + \frac{1}{2}K\eta^2 + \frac{1}{6}Q\eta^3 + .. \quad (1)$$

with, $\eta = (\rho-\rho_0)/3\rho_0, L$ is slope parameter, and K is symmetry energy curvature. The surface properties of finite nuclei are obtained by folding the nuclear matter symmetry energy and its related quantities with the weight function $|f(x)|^2 = -\left(\frac{1}{\rho_0(x)}\frac{d\rho(r)}{dr}\right)_{r=x}$ with the help of CDFM [3, 4]. Where $\rho_0(x), \rho(r)$ is Flucton's density and density of a nucleus respectively:

$$O = \int_0^\infty dx|f(x)|^2 X \qquad (2)$$

where, $X = C(\rho), L = 3\left(\frac{P}{\rho}\right)_{\rho_0}, K$
$O = S, P, K_{sym}$ respectively.

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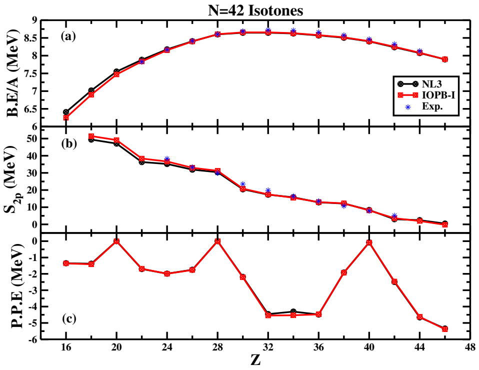

FIG. 1: Variation of binding energy per nucleon (a), two proton separation energy (b), and proton pairing energy (c) with Z for NL3 (black) and IOPB-I (red) parameter.

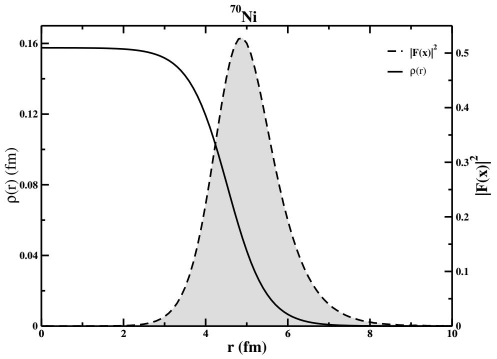

FIG. 2: The density distribution of ^{70}Ni and its weight function $|F(x)|^2$.

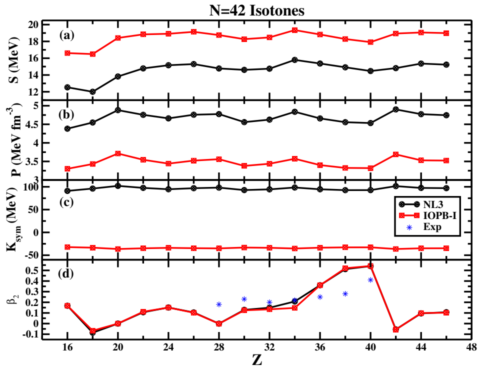

FIG. 3: Trends of symmetry energy(S) (a), neutron pressure (P) (b), symmetry energy curvature (K_{sym}) (c), and deformation (d) with Z for two sets of force parameter NL3 and IOPB-I.

Results and Discussions

The bulk properties of N=42 isotones, such as binding energy per nucleon ($B.E/A$), two proton separation energy (S_{2p}), and proton pairing energy ($P.P.E$), shown in Panels (a), (b), and (c) of Figure 1, respectively, are calculated within RMF with NL3 and IOPB-I forces. These results are in good agreement with each other as well as with the experimental results [1] wherever available, along with some change of behavior/kinks at Z=20,28, and 40 correspond to the shell/sub-shell closure/magic number.

Figure 2 displays the density distribution of ^{70}Ni and its weight function $|F(x)|^2$ as a representative case, and it is clear from the figure that $|F(x)|^2$ has maximum near the surface of a nuclear system. Thus, the contribution to symmetry energy is maximum from the surface. Figure 3 presents the symmetry energy S (a), neutron pressure P (b), symmetry energy curvature K_{sym} (c), and deformation β_2 (d) of the chosen isotonic chain with atomic number Z. It is inferred from the figure that the surface properties, namely S, P, and K_{sym}, change their behavior accordingly with the behavior of β_2. The S value of NL3 is found to be smaller than IOPB-I; this is due to the fact that below ρ_0, $C(\rho)$ of NL3 is smaller than that of IOPB-I [1].

The future study of correaltion of these studied properties along with the surface and volume components and their ratios with the ground state properties have been planned. This study can be used to understand (theoretical and experimental) aspects of nuclear systems far from the β stability line.

References

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