Effect on symmetry energy at shell/sub-shell closure within relativistic mean-field formalism

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Introduction

One of the most crucial topics in the present nuclear physics is the pursuit for the existing limit of nuclear drip-line. In recent years, the advancement of radioactive ion-beam has opened up the new prospect of nuclear structural study on exotic nuclei while exploring the effect on strong nuclear interaction from the isospin asymmetry [1, 2]. Nuclear bulk parameters such as binding energy, quadrupole deformation, root-mean-square charge radius, and others are referred to as standard observable and can predict shell and/or sub-shell closure in nuclei near the stability line. On the other hand, moving away from the $\beta-$ stability line towards the drip line implies an extreme case of isospin asymmetry and leads to the failure of these classical observables to predict the shell/sub-shell closures.

Symmetry energy can be reflected in the change of binding energy of a nuclear system with the variation in isospin asymmetry. Hence, the dependence of symmetry energy on isospin asymmetry serves as a crucial tool in understanding the properties of nuclei away from the β-stability line. Symmetry energy being a quantity of infinite nuclear matter, cannot be directly translated to finite nuclear matter. One possible method to estimate the symmetry energy and bring it into the purview of finite nuclear matter is through the use of the coherent density fluctuation method (CDFM), which employs the observables related to symmetry energy in its formalism. In the present study, the symmetry energy along with its surface and volume components are estimated for Titanium isotopic chain using the NL3 parameter set within the relativistic mean-field formalism (RMF) [3].

Theoretical Formalism

The effective symmetry energy is estimated by employing the coherent density fluctuation method (CDFM) [4, 5] and can be expressed as:

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

where $\mathcal{F}(x)|^2$ implies the weight function and $S^{NM}(x)$ refers to the symmetry energy at local density. Here, the weight function $\mathcal{F}(x)|^2$

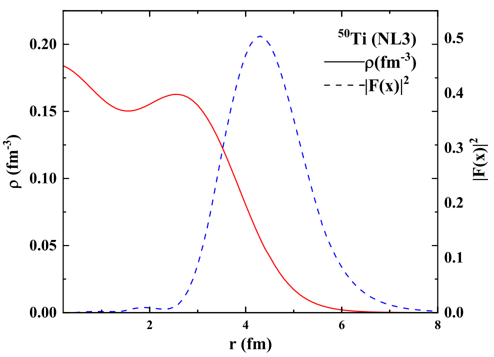

FIG. 1: The weight function $\mathcal{F}(x)|^2$ and density ρ with respect to nuclear nuclear distance r for ^{50}Ti (NL3).

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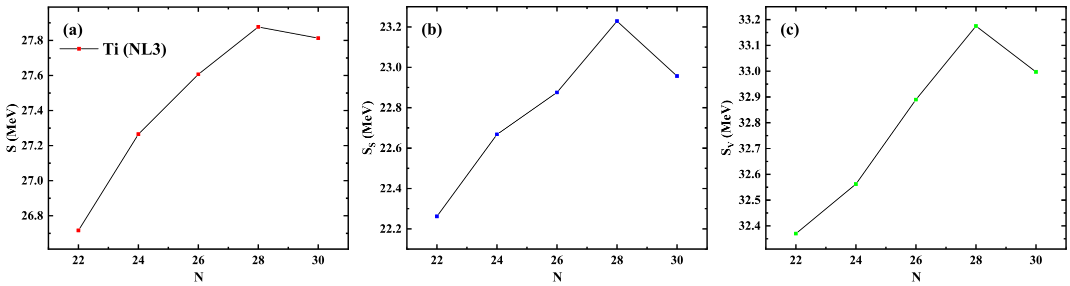

FIG. 2: The (a) symmetry energy (S), (b) surface (S_S) and (c) volume symmetry energy (S_V) with respect to neutron number for Titanium isotopes within NL3 parameter set

is calculated from the expression

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

Employing the Bethe–Weizsäcker liquid drop model, the volume (S_V) and surface component (S_S) of symmetry energy (S) can be calculated from [6, 7],

$$S_V = S\left(1+\frac{1}{\kappa A^{1/3}}\right); S_S = \frac{S}{\kappa}\left(1+\frac{1}{\kappa A^{1/3}}\right), \quad (3)$$

where $\kappa = \frac{S_V}{S_S}$.

Results and discussion

First, using the CDFM, we calculate the weight function of Titanium (Z=22) isotopes using the RMF densities. Fig. 1 provides a spherical equivalent density and weight function of ^{50}Ti as a function of nuclear distance. It can be noted that the weight function forms a bell shape and has maxima near the surface region, validating the importance of surface density in the symmetry energy.

Fig. 2 highlights the symmetry energy along with surface and volume components respectively for Titanium nuclei as a function of neutron number. We find sharp discontinuity or kink at the classical magic number $N = 28$ for all the three parts of Fig.2, that is symmetry energy, surface and volume symmetry energy, which implies the existence of shell/sub-shell closure in the Titanium isotopic chain [8]. The use of density-dependent symmetry energy in this study verifies the significance of isospin asymmetry in evaluating the magicity along the isotopic chain, and it also enhances our understanding of properties associated with nuclei near the drip line.

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