Comparative Study of Symmetry Energy and its Coefficients within CDFM and LDA

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Introduction

Symmetry energy is an important entity in different disciplines of nuclear physics, such as heavy-ion reactions, physics of neutron stars, and ground-state nuclear structure properties, including in locating the drip-line of the nuclear system [1]. Since the symmetry energy has a direct connection with the isospin asymmetry of the nuclear matter and the availability of the exotic beams, it has raised an interest to study the nuclei far from the β-stability line/drip-line nuclei. Due to different numbers of protons and neutrons, the equation of state (EOS) of asymmetric nuclear matter remains subtle to date. The measurement of symmetry energy through experiment is not directly accessible, and it has to be obtained indirectly from the related observables. One of the sensitive probes for the symmetry energy is neutron skin-thickness[1].

The significance of symmetry energy and its density-dependence has motivated us to do its comparative study for N=38 isotones within the coherent density fluctuation model (CDFM) and the local density approximation (LDA). These two different density-dependent models allow us to calculate the symmetry energy and its related observable (neutron pressure, symmetry energy curvature) for the finite nuclei from the corresponding infinite nuclear matter observables. The key difference between these two approaches is that in the CDFM, only surface part of the density distribution has significant contribution, while within the LDA, the whole density profile has its impact in determining the symmetry energy. The densities used in the CDFM and LDA are obtained from the relativistic mean-field model (RMF) [3].

Formalism

The symmetry energy of nuclear matter (C^{NM}) is the second-order derivative of binding energy per nucleon with respect to asymmetry coefficient α. Further, the neutron pressure (P^{NM}) and symmetry energy curvature (K_{sym}^{NM}) of nuclear matter are obtained, respectively, from the slope parameter and second order derivative of C^{NM} with respect to baryonic density. In LDA [1], the expression to calculate the symmetry energy S at the local density $\rho(r)$ of nuclei is as follows:

$$S\left(\frac{N-Z}{A}\right) = \frac{1}{A}\int \rho(r)C^{NM}[\rho(r)]\alpha^2(r)dr \quad (1)$$

where, N, Z, and A are the neutron, proton, and mass numbers of the nuclei, respectively. Neutron pressure (P) and symmetry energy curvature (K_{sym}) of nuclei can be find out by replacing the $C^{NM}[\rho(r)]$ with P^{NM} and K^{NM} in the Eq.(1).

In CDFM, the S, P, K_{sym} for a finite nuclei can be obtained by folding the C^{NM}, P^{NM}, and K_{sym}^{NM} with the weight function $|f(x)|^2 = -\left(\frac{1}{\rho_0(x)}\frac{d\rho(r)}{dr}\right)_{r=x}$ as:

$$F = \int_0^\infty dx|f(x)|^2 Y \quad (2)$$

where, $\rho_0(x)$ is the Flucton's density, $Y = C^{NM}(\rho), P^{NM}, K_{sym}^{NM}$ and $F = S, P, K_{sym}$ respectively.

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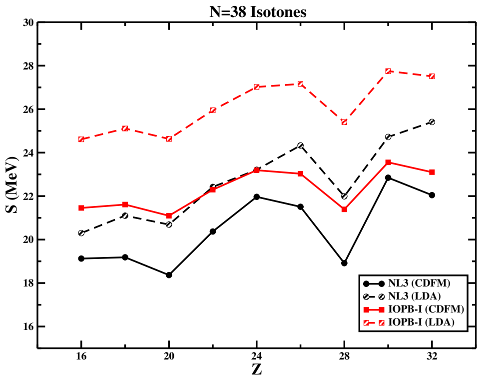

FIG. 1: Variation of Symmetry energy S with Z, obtained from the CDFM (solid line) and LDA (dotted lines) for NL3 (black) and IOPB-I (red) parameters.

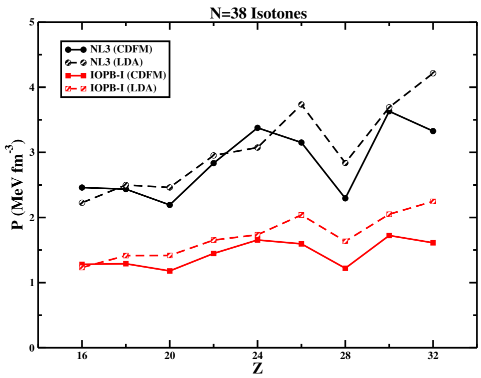

FIG. 2: Neutron Pressure P changes with Z for NL3 and IOPB-I.

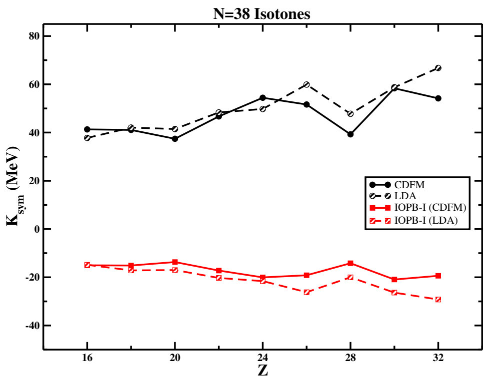

FIG. 3: Trends of symmetry energy curvature (K_{sym}) with Z for NL3 and IOPB-I.

Results and Discussions

In the present study, we have calculated the S, P, K_{sym} for N=38 isotones. The RMF model is used to calculate the densities of the isotones along with the bulk properties with force parameters, NL3 and IOPB-I.

Figure 1 presents the symmetry energy S for the chosen isotonic chain obtained from the CDFM and LDA with NL3 and IOPB-I parameters. It can be seen from the figure that the S value increase with Z. There is a large change in slope of the curves at Z=20, and 28, which corresponds to the proton magic numbers. It is worth to observe here that the S value in the case of CDFM is lower than that of LDA due to the significant contribution from surface part of the density only. It can also be observed from the figure that the changes in curve for CDFM is more than that of LDA corresponding to both the force parameters. Figure 2, and Figure 3 show the neutron pressure P, and symmetry energy curvature K_{sym} within LDA and CDFM for NL3 and IOPB-I with Z. It is clear from the figures that symmetry energy and neutron pressure are reciprocal to each other for NL3 and IOPB-I parameters. It is also observed from the last two figures that the changes in the curves are more sharply at proton magic numbers.

From this study, it can be concluded that the CDFM is comparatively better model to anticipate the shell structure in an isotonic/isotopic series over the LDA as in CDFM curves, there are prominent changes at magic numbers. A more detailed investigation about the dependence on symmetry energy is to be determined shortly.

References

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