Nuclear Symmetry Energy and Surface Properties of Neutron Rich Exotic Nuclei

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Introduction

The advancement in the experimental facilities such as Jyavãskylã (Finland), ORNL (United States), CSR (China), FAIR (Germany), RIKEN (Japan), GANIL (France), GSI (Germany), FLNR (Russia) and FRIB (United States) has already opened new possibilities of exploring the production of various exotic nuclei and their properties under the extreme conditions of large isospin asymmetry. By virtue of the neutron-proton asymmetry in finite nuclei, one can resolve some of the basic components of the equation of state (EoS) of nuclear matter such as the symmetry energy and the slope parameter at nuclear saturation density ρ_0 [1]. Further, these nuclear matter parameters are involved in the bulk properties of finite nuclei such as binding energies, relative nuclear radii and nucleonic density distributions [2, 3]. Here, we have established a correlation between the neutron skin thickness and nuclear matter properties, such as symmetry energy, the neutron pressure and the asymmetric compressibility in the isotopic chain of neutron rich medium mass nuclei.

Theoretical formalism

In the present study, we have used the microscopic self-consistent relativistic mean field (RMF) theory with NL3* force [4, 5] to investigate the ground state bulk properties such as binding energy, rms charge radius, nuclear qudrupole deformation β_2, nuclear density distribution $\rho(r_\perp, z)$, and the single particle energy. Once we have the density in hand, we estimate the nuclear matter observables using these densities in the framework of coherent density functional method (CDFM) [2]. Following the (CDFM) approach, the symmetry energy S_0, the pressure p_0, and the curvature K_0 for a finite nucleus can be written as [2, 3],

$$S_0 = \int_0^\infty dx|f(x)|^2 S^{NM},$$
$$p_0 = \int_0^\infty dx|f(x)|^2 p_0^{NM},$$
$$K_0 = \int_0^\infty dx|f(x)|^2 K_0^{NM}, \quad (1)$$

where, S^{NM}, p_0^{NM}, and K_0^{NM} denotes the symmetry energy, the neutron pressure and the incompressibility of asymmetric nuclear matter. The calculated densities from the RMF (NL3*) are used for the estimation of the weight function $|f(x)|^2$ in Eqn. (1).

Results and Discussions

The RMF calculations furnish principally nuclear structure properties, based on the basic ingredients such as the quadrupole moment Q_{20}, nucleon density distribution $\rho(r_\perp, z) = \rho_p(r_\perp, z) + \rho_n(r_\perp, z)$, and the root-mean-square nuclear radius. Nevertheless, the present study demonstrates the applicability of the RMF to the nuclear structure study of the neutron drip-line. We estimate the neutron skin thickness ΔR of nuclei in a given isotopic chain using the neutron and proton radii obtained from the RMF (NL3*) force. The symmetry energy S_0 for a given nucleus is calculated within the CDFM using the weight

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function $|f(x)|^2$ (obtained from the self consistent density) using Eqn. (1). We show the symmetry energy S_0 as a function of neutron skin thickness in Fig. 1 for $^{72-88}$Ni, as a representative case. The results from Skyrme-Hartree-Fock (SHF) + BCS with LNS force are also given for comparison, where available. From the figure, we observe a smooth growth of S_0 until the neutron number (N = 50) and then a linear decrease of S_0 where the neutron-skin thickness of the isotopes increases.

Comparing the results of RMF with the SHF, we also found a similar behavior of the symmetry energy with respect to the skin thickness. Careful inspection shows that the neutron skin thickness obtained from the RMF (NL3*) is a slightly overestimated when compared to that of LNS force. We also found similar predictions for $^{70-86}$Fe, $^{74-90}$Zn, $^{76-92}$Ge, $^{78-94}$Se, and $^{80-96}$Kr nuclei. Further, we also we illustrate a possible correlation of the neutron skin thickness ΔR with the neutron pressure p_0 and the nuclear compressibility K_0 for the isotopic chain of Fe−, Ni−, Zn−, Ge−, Se−, and Kr− nuclei. From the estimated results, we found that the neutron skin thickness of the isotopes correlates almost linearly with p_0 and K_0, as does S_0. In other words, similar to the symmetry energy, we also find a peak in the neutron pressure p_0 and a minimum in the compression modulus K_0 for semi-magic nuclei at N = 50. More details of the work will be present in the upcoming symposium.

Summary and Conclusions

In this theoretical study, we establish a correlation between the neutron skin thickness and the nuclear symmetry energy for the even−even isotopes of Fe, Ni, Zn, Ge, Se and Kr nuclei within the framework of the axially deformed self-consistent relativistic mean field model. The coherent density functional method is used to formulate the symmetry energy, the neutron pressure and the asymmetric compressibility of finite nuclei as a function of the nuclear radius. From this analysis, we

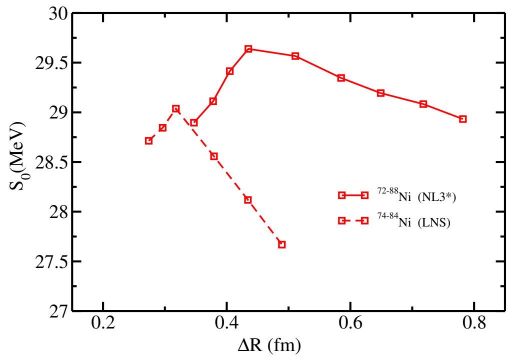

FIG. 1: The symmetry energy S_0 for $^{72-88}$Ni isotopes as a function of neutron skin thickness ΔR for the RMF (NL3*) force. The Skyrme-Hartree-Fock + BCS results for the LNS force [3] are also given for the comparison, where available. See the text for details.

found a notable signature of a shell closure at $N = 50$ in the isotopic chains of Fe, Ni, Zn, Ge, Se and Kr nuclei. The present study reveals a strong interrelationship between the equation state of nuclear matter and the neutron skin thickness of finite nuclei.

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