Temperature-dependence of symmetry energy and its volume and surface components in some rare earth nuclei

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Introduction

Symmetry energy is one of the hot issues of the contemporary nuclear physics, being the fundamental ingredient of equation of state of asymmetric nuclear matter. It has significant influence upon different nuclear phenomena extending from the dynamics of asymmetric heavy ion collisions to the neutron stars [1, 2]. The availability of exotic nuclei with advent of radioactive ion beam facilities act as major driving force to investigate the symmetry energy and its density dependence. It is experimentally probed via study of heavy ion collisions, nucleon flow, isospin diffusion measurements etc. [3, 4].

The knowledge of symmetry energy is inevitable to understand the ground state properties of exotic nuclei. Danielewicz has shown that for the proper description of properties of neutron drip-line nuclei, it is crucial to take into account the surface symmetry contribution in addition to volume contribution [5]. In addition, it is noted that an increase in excitation energy leads to shape and density change and hence the change in the symmetry energy. Moreover, the temperature (T) dependence of symmetry energy is crucial to understand the heavy ion collisions physics. With this impetus, we have explored the T-dependence of symmetry energy and its volume and surface contributions in the isotopic chains of rare earth Nd and Sm nuclei with N = 82-126 within the framework of coherent density fluctuation model (CDFM) [6].

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Formalism

The temperature-dependent symmetry energy S within CDFM is calculated by

$$S(T) = \int_0^\infty dx|F(x,T)|^2 S[\rho(x,T)], \quad (1)$$

where the weight function $|F(x,T)|^2$ depends on the density distribution

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

The axially deformed temperature-dependent densities are taken from RMF model [7] with NL3 and IOPB-I parameter sets and are converted into spherical equivalent densities by following the method of Ref. [8] for further use in Eq. (2). The expression for ratio κ within CDFM following [5] is,

$$\kappa(T) = \frac{3}{R\rho_0}\int_0^\infty dx|F(x,T)|^2 x\rho_0(x) \times \left[\left(\frac{S(\rho_0)}{S(\rho(x,T))}\right) - 1\right] \quad (3)$$

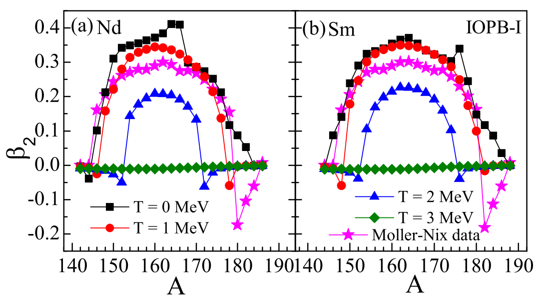

FIG. 1: The temperature-dependence of variation of quardupole deformation β_2 with mass number in isotopic chains of (a)Nd and (b)Sm and comparison with Möller Nix data [9]

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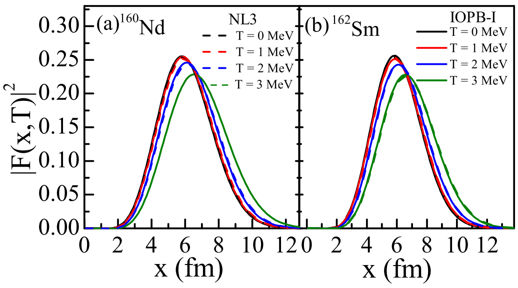

FIG. 2: The temperature-dependent weight function $\mid F(x,T) \mid^2$ of (a)^{160}Nd and (b)^{162}Sm with NL3 and IOPB-I parameter sets.

The segregation of symmetry energy into volume and surface components and other related details are discussed in Ref. [10].

Results and discussion

We discuss the effect of temperature on the shape of nuclei in the isotopic chains of Nd and Sm nuclei, as shown in Fig. 1. It is noted that at T = 0 MeV, quadrupole deformation β_2 increases with A and becomes maximum at N = 100 and decreases thereafter. At T = 1, 2 MeV the magnitude of β_2 decreases comparatively and at T = 3 MeV, the nuclei become spherical in shape. Fig. 2 shows the effect of temperature on the weight function of (a)^{160}Nd and (b)^{162}Sm nuclei. The peak in the curve shifts downwards and towards the right with an increase in temperature. It occurs due to change in density with increasing temperature. Further, these weight functions are used to find the symmetry energy (Eq. 1) and its components.

The thermal evolution of symmetry energy S and its volume S_V and surface S_S components is shown in Fig. 3. At low temperatures, the rise and fall trend is seen in S, S_V and S_S with a peak at neutron number N = 100 [10]. This peak signifies that more energy is needed to convert a neutron into proton and is a signature of deformed shell closure/magic number. However, the scenario changes at higher temperatures T = 1, 2 MeV where the magnitude of the peak decreases and finally at T = 3 MeV the peak disappears and a plateau is seen in the studied quantities. It is interesting to note that the evolution of S, S_V and S_S is closely related to that of β_2 (see Fig. 1). Therefore, the disappearance of the peak at T = 3 MeV may be due to shape change, in addition to shell quenching at higher T. It is also seen that surface symmetry energy is more sensitive to temperature change than volume symmetry energy.

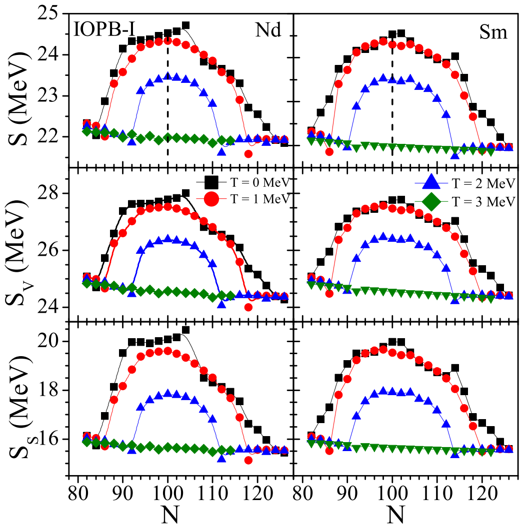

FIG. 3: Temperature-dependence of variation of symmetry energy (S), volume (S_V) and surface symmetry energy (S_S) with neutron number for Nd (left panel) and Sm (right panel) nuclei with IOPB-I parameter set.

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