Density dependence of symmetry energy in deformed ^{162}Sm nucleus

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Introduction

The nuclear symmetry energy (NSE) describes the isospin-dependence of in-medium nucleon–nucleon interactions, i.e., neutron–neutron and proton–proton interactions versus neutron–proton interactions. But due to incomplete knowledge of isospin-dependence of nuclear force, the investigations of NSE at different densities using different models and experimental constraints can provide the information about the isospin character of the nuclear interaction. The NSE at different densities is probed via the analyses of HI reactions, nucleon flow, isospin diffusion measurements, etc.[1–2]. Also, the measurement of neutron skin size helps to constrain the NSE since the density derivative of NSE is correlated with skin size [3]. The astrophysical observations of neutron stars also facilitate to investigate the properties of nuclear matter under extreme isospin conditions.

Theoretical Formalism

The calculation of symmetry energy of deformed nucleus demands the conversion of deformed density into the spherical equivalent one. The procedure followed to get the spherical equivalent density has significant influence upon the symmetry energy calculations. RMF theory is one of the microscopic approaches to solve many body problems of nuclear system. In the RMF model, the nucleons are assumed to interact through the exchange of mesons. The details of the RMF model and the NL3 parameter sets can be found in Refs. [4] and [5]. The axially deformed density obtained from RMF formalism has been modified into the spherical equivalent density by using different methods described as below:

- **Gaussian Fitting**

The term represented as $\rho(r_\perp, z)$ is the deformed density which is get changed to $1-D$ density as $\rho(r_\perp)$, with $r_\perp = \sqrt{(x^2+y^2)}$ by solving the integration with respect to z, taking the limit of whole space as worked out in Refs. [6] and [7]

$$\rho(r_\perp) = \int_{-\infty}^{\infty} \rho(r_\perp, z)dz.$$

After that the resultant density $\rho(r_\perp)$ is taken as a two point Gaussian function as given below

$$\rho(r) = \sum_{i=1}^{2} c_i \exp[-a_i r^2],$$

where, c_i are the coefficients and a_i are the ranges for corresponding nuclei.

- **Woods-Saxon Fitting**

The position vector $r = (x^2+y^2+z^2)^{\frac{1}{2}}$ is utilized to get the spherical equivalent density which is a function of r only. Here the calculated density will not vary. The $r_\perp$ and z they add themselves and provide an average value of r for a certain density distribution. This resultant density is taken as Woods–Saxon form

$$\rho(r) = \frac{\rho_0}{\left(1+\exp\left[\frac{(r-R)}{a}\right]\right)}.$$

- **Multipole Expansion**

The multipole decomposition of the density can be written in terms of even values of the multipole index λ as [8]

$$\rho(r_\perp, z) = \sum_\lambda \rho_\lambda(R) P_\lambda(cos\theta),$$

where, $r_\perp$ and z are the cylindrical coordinates of the radial vector R. The monopole term of the density distribution is used in the expansion equation for the calculation of the weight function $|F(x)|^2$ for simplicity. For a deformed nucleus, the peak of $|F(x)^2|$ does indeed depends on the angle. However, the density also depends on the angle in such a manner that the density at the peak of $|F(x)^2|$ is almost constant. The effect of the multipole component in the expansion can thus be neglected.

Results and Discussions

The variation in symmetry energy value for deformed ^{162}Sm nucleus calculated within the Coherent density fluctuation model (CDFM)[9-10] using the spherical equivalent density from RMF model as an input [4]. The ^{162}Sm density obtained from RMF model with NL3 parameter set is axially deformed. The variation of this density along $r_\perp$ and z-direction for a corresponding particular value of z and $r_\perp$, is plotted in Fig. 1. In this figure this axially deformed density is compared with the density as calculated by spherical RMF code. In Fig. 2, the spherical equivalent density of ^{162}Sm obtained by using various ways is represented with the NL3 force parameter which is again compared with the pure spherical density. Form this figure it is cleared that the Woods–Saxon fitting method fitted the density well. And also the multipole expansion method is very close to the pure spherical density extracted from the spherical RMF code. Further in the Gaussian fitting method the density is little bit more at the center than the normal saturation density.

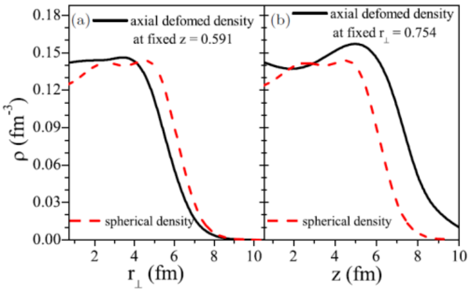

Fig.1: The axially deformed ^{162}Sm densities with NL3 force parameter (a) along $r_\perp$ direction with a certain z-values (b) along z-direction with a certain $r_\perp$-values. The comparison of deformed densityalong $r_\perp$ and z-directions has been made with pure spherical density with NL3 parameter. For spherical density the X-axis represents the r (fm) in (a, b).

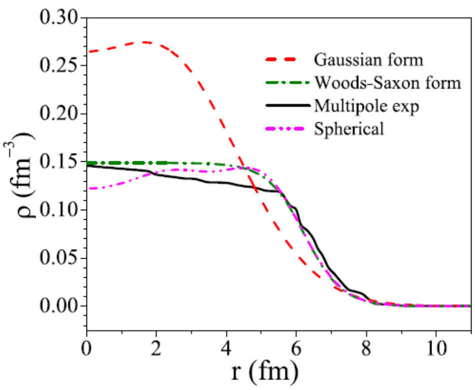

Fig.2: The varioation of spherical equivalent density ρ taken by the help of various methods for axially deformed ^{162}Sm nucleus.

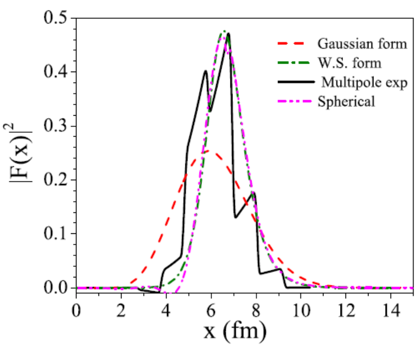

Fig.3: The change of $|F(x)|^2$ calculated by the help of spherical densities taken from various methods for the deformed ^{162}Sm.

Method	S
Pure spherical	25.78
Gaussian form	27.42
Woods–Saxon form	25.96
Multipole expansion	24.98

Table 1: The symmetry energy values of 162Sm nucleus by using spherical equivalent densities obtained from the deformed density by different methods with $\gamma = 0.3$.

Conclusion

The deformed and spherical RMF density for ^{162}Sm with NL3 parameter set have calculated. The deformed density is converted into spherical equivalent using two Gaussian and Woods–Saxon fitting. Also, the usually performed multipole expansion method is used to obtain the spherical equivalent density keeping the total mass conserved of ^{162}Sm. The results present a variation of about 9% in the symmetry energy with different methods of getting spherical equivalent density.

References

[1] L.W. Chen, C. M. Ko and B. A. Li, *Phys. Rev. Lett.* **94** (2005) 032701.

[2] X.-H. Fan, G.-C. Yong and W. Zuo, *Phys. Rev. C* **97** (2018) 034604.

[3] C. J. Horowitz *et al.*, *Phys. Rev. C* **63** (2001) 025501.

[4] R. J. Furnstahl , B. D. Serot and H. B. Tang, *Nucl. Phys. A* **598** (1996) 539.

[5] R. J. Furnstahl, B. D. Serot and H. B. Tang, *Nucl. Phys. A* **615** (1997) 441.

[6] A. Bhagwat and Y. K. Gambhir, *Phys. Rev. C* **69** (2004) 014315; A. Bhagwat and Y. K. Gambhir, *Phys. Rev. C* **77** (2008) 027602.

[7] A. Shukla, B. K. Sharma, R. Chandra, P. Arumugam and S. K. Patra, *Phys. Rev. C* **76** (2007) 034601; M. K. Sharma, R. N. Panda, M. K. Sharma and S. K. Patra, *Phys.Rev. C* **93** (2016) 014322.

[8] Z. Patel *et al.*, *Phys. Rev. Lett.* **113** (2014) 262502.

[9] A. N. Antonov, D. N. Kadrev and P. E. Hodgson, *Phys. Rev. C* **50** (1994) 164.

[10] M. K. Gaidarov, A. N. Antonov, P. Sarriguren and E. M. deGuerra, *Phys. Rev. C* **85** (2012) 064319.