Density Slope Parameter at subsaturation densities from electric dipole polarisability

S. K.Tripathy* and D. Behera†
Department of Physics, Indira Gandhi Institute of Technology, Sarang, Dhenkanal, Odisha, 759146, INDIA

Introduction

A lot of theoretical and experimental efforts have been made to constrain the Nuclear Symmetry Energy (NSE) $E_s(\rho)$ and its density slope $L(\rho) = 3\rho\frac{\partial E_s(\rho)}{\partial\rho}$. While the NSE at saturation density is constrained as $E_s(\rho_0) = 32 \pm 4$ MeV, there still persists uncertainty in constraining its density slope parameter $L(\rho_0)$. There have many attempts to constrain $L(\rho_0)$ from different studies such as neutron skin thickness, isovector giant dipole and quadrupole resonance and electric dipole polarisability. However there have been very few attempts to constrain the density slope parameter at subsaturation densities. In this context, finite nuclei like ^{208}Pb with an density of $\rho_c = 0.11 fm^{-3}$ can be more useful for the study of NSE at subsaturation densities. $L(\rho_c)$ can be instrumental in the determination of the neutron skin thickness and the core-crust transition density in neutron stars.

The electric dipole polarisability α_D is believed to an effective probe for the constraining the density dependence of NSE. α_D for ^{208}Pb is measured to be $20.1 \pm 0.5 fm^3$ at the Research Centre for Nuclear Physics (RCNP). Zhang and Chen, in their work [1] have used an approximate formula to constrain the density slope parameter at a density $\rho_c = 0.11 fm^{-3}$ in the range $L(\rho_c) = 48.6 \pm 7.9$ MeV. In the present work, we have used the theoretical technique used in Ref.[1] to constrain the density slope parameter at subsaturation densities.

*Electronic address: tripathy_sunil@rediffmail.com
†Electronic address: dipadolly@rediffmail.com

Formalism

Within the frame work of droplet model, the electronic dipole polarisability α_D of a nucleus of mass A can be expressed as [2]

$$\alpha_D = \frac{\pi e^2}{54}\frac{A < r^2 >}{E_s(\rho_0)}\left[1 + \frac{5}{3}\frac{E_s(\rho_0) - a_s(A)}{E_s(\rho_0)}\right], \quad (1)$$

where $a_s(A)$ is the symmetry energy coefficient of the finite nucleus and $< r^2 >^{1/2}$ is the root mean square radius. $a_s(A)$ can be taken as $E_s(\rho_c)$ where $\rho_A \simeq \rho_c$. Expanding $E_s(\rho_0)$ around ρ_c and retaining upto the 1st order term in $\epsilon_c = \frac{\rho_0 - \rho_c}{3\rho_c}$, Zhang and Chen obtained

$$E_s(\rho_0) \simeq E_s(\rho_c) + L(\rho_c)\epsilon_c. \quad (2)$$

A substitution of (2) in (1) yields an approximate formula for α_D:

$$\alpha_D = \alpha_{D0}\left[1 + \frac{5}{3}\frac{L(\rho_c)\epsilon_c}{E_s(\rho_0)}\right], \quad (3)$$

where, $\alpha_{D0} = \frac{\pi e^2}{54}\frac{A<r^2>}{E_s(\rho_0)}$ is the value of α_D for a vanishing density slope $L(\rho_c)$. The above relation clearly shows a linear correlation between α_D and $L(\rho_c)$ for a given $E_s(\rho_0)$.

Results and Discussion

The calculated value of $E_s(\rho_0)$ are shown as a function of $L(\rho_c)$ in the Figure 1. It is clear from the figure that, $E_s(\rho_0)$ increases steadily with $L(\rho_c)$ and we can get an acceptable range for its value within $9 \leq L(\rho_c) \leq 62$ MeV. Here, we assumed $E_s(\rho_c) = 26.65 MeV$ for ^{208}Pb basing upon the recent constraint $E_s(\rho_c) = 26.6 \pm 0.2$ MeV.

In Figure 2, the calculated α_D is shown as a function of $L(\rho_c)$ using different forms of

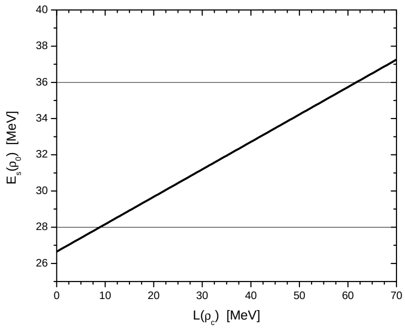

FIG. 1: NSE at saturation density as calcualted from eq.(2).

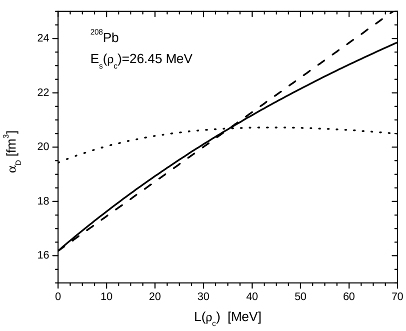

FIG. 2: α_D for ^{208}Pb from different formulations. ()See text for details.)

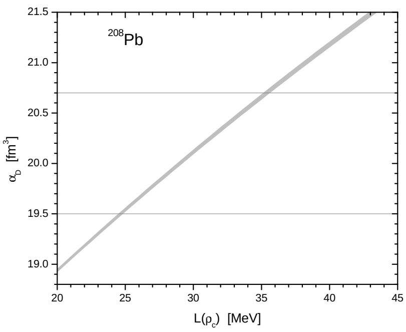

FIG. 3: α_D for ^{208}Pb for the range of $E_s(\rho_c)$ compared with the experimental values.

the approximate formulation. It is clear from the figure that, the behaviour of α_D depends on the assumption for $E_s(\rho_0)$. For a constant $E_s(\rho_0)$ (say 32 MeV) in eq.(3), there occurs an obvious linear correlation between α_D and $L(\rho_c)$ (dashed line in Fig.2). For a constant α_{D0} in eq. (2), α_D becomes slightly stiffer initially and then becomes softer (solid curve in Fig.2). α_D is observed to have a much higher value for low $L(\rho_c)$ but almost saturates for higher $L(\rho_c)$ (dotted curve in Fig. 2), when we use eq.(2) instead of a constant $E_s(\rho_0)$.

In Figure 3, we have shown α_D calculated from eq. (3) with a constant $E_s(\rho_0)$. The experimental data $\alpha_D = 20.1 \pm 0.5 fm^3$ have been used for the purpose. The density slope parameter can be constrained in the range $24. \leq L(\rho_c) \leq 35.5$ MeV.

Conclusion

We have analysed the theoretical technique used to calculate the electronic polarisability in heavy nuclei in the context of constraining the subsaturation density slope parameter. The expression used in a recent work by Zhang and Chen for this purpose has been analysed in detail. Since the electronic polarisability is sensitive to the density slope, care must be taken while using the said expression.

References

[1] Zhang Z and Chen L W, 2014 Phys. Rev. C **90**, 064317.
[2] Roca-Maza X et al., 2013 Phys. Rev. C **88**, 024316.