Nuclear Symmetry Energy at suprasaturation densities

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Introduction

Density dependence of Nuclear Symmetry Energy(NSE), $E_s(\rho)$, has been a subject of intensive investigation in recent times because of its importance in understanding different issues in nuclear Physics and astrophysics. An expansion of $E_s(\rho)$ around the saturation density ρ_0 reads as

$$E_s(\rho) = E_s(\rho_0) + \frac{L}{3}\left(\frac{\rho-\rho_0}{\rho_0}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho_0}\right)^2 + \cdots, \quad (1)$$

where $L = 3\rho_0 \frac{\partial E_s(\rho)}{\partial \rho}|_{\rho=\rho_0}$ and $K_{sym} = 9\rho_0^2 \frac{\partial^2 E_s(\rho)}{\partial \rho^2}|_{\rho=\rho_0}$ are the slope and curvature parameters of $E_s(\rho)$ at ρ_0. Upto 2nd order in density, the suprasaturation density behaviour of NSE depends on these parameters L and K_{sym}. While the nuclear symmetry energy at normal nuclear matter density, $E_s(\rho_0)$ is more or less tightly constrained in the range $E_s(\rho_0) = 31.6 \pm 2.2$ MeV, the knowledge of symmetry derivatives L and K_{sym} is still very poor which pushes the behaviour of $E_s(\rho)$ into uncertainty. The symmetry slope parameter L is constrained from neutron thickness of heavy nuclei in the range 59 ± 13.0 MeV and from giant dipole resonance in ^{208}Pb in the range 43 ± 26 MeV. The curvature parameter K_{sym} is rather poorly constrained in many calculations in the range $-300 \leq K_{sym} \leq 125$ MeV.

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Different parametrized forms for $E_s(\rho)$ have been proposed in recent times to understand its density dependence at densities away from saturation. Some popular parametrizations are (i) $E_s(\rho) = E_s(\rho_0)u^\gamma$ with $\gamma = 0.69 - 1.05$ [1] and (ii) $E_s(\rho) = 12.5u^{2/3} + C_p u^\gamma$ with $\gamma = 0.4 - 1.05$ [2]; $u = \frac{\rho}{\rho_0}$. In a recent work, Dong et al. [3] proposed a form of $E_s(\rho)$ as $E_s(\rho) = 17.47u^{2/3} + C_1 u + C_2 u^{1.52}$ and fitted the parameters from a correlation between K_{sym} and L calculated from different mean field interactions. In the process, they have modified the kinetic contribution to NSE. In the present work, we have suggested a similar form for NSE but kept the kinetic contribution intact as obtained from a non relativistic approach to the Fermi energy.

Correlation between L and K_{sym}

From the calculation of the symmetry slope parameter and the curvature parameter using different sets of Skyrme type interaction, one can obtain a linear relationship between these two parameters. In Fig.1 we have plotted the K_{sym} as function of L as calculated from different Skyrme type interactions. The Figure clearly shows a linear correlation between these two parameters. A linear fitting of the calculated values to a relation $K_{sym} = a + bL$ returns us the values for the parameters a and b as $a = -308.42 \pm 12.48$ MeV and $b = 3.31 \pm 0.16$.

We can assume DDM3Y inspired shape for $E_s(\rho)$,

$$E_s(\rho) = E_s^{kin}(\rho) + E_s^{int}(\rho) \quad (2)$$

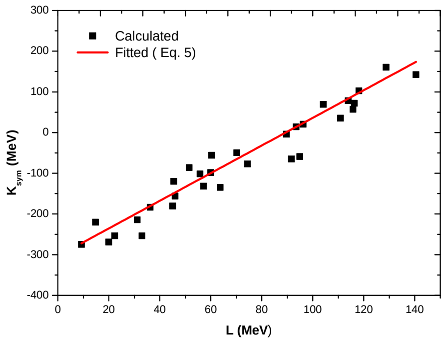

FIG. 1: Correlation of K_{sym} with L.

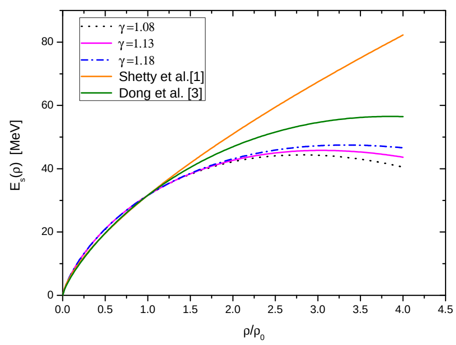

FIG. 2: Density dependence of $E_s(\rho)$.

with

$$E_s^{kin}(\rho) = C_k u^{2/3}, \qquad (3)$$
$$E_s^{int}(\rho) = C_1 u + C_2 u^{\gamma} \qquad (4)$$

being respectively the kinetic and interaction parts of NSE. The parameters C_1, C_2 and γ can be fitted from some physical basis. $C_k = \frac{3}{5} E_{f_0} \left(2^{2/3} - 1\right)$ where E_{f_0} is the nuclear matter Fermi energy.

We can have a correlation for K_{sym} and L for the assumed form of $E_s(\rho)$ as

$$K_{sym} = 3\gamma \left[L - 3E_s(\rho_0) + C_k\right] - 2C_k. \qquad (5)$$

From a fitting of this relation (Eq.5) with the calculated values from Skyrme type interactions as in Fig.1, we obtain $\gamma = 1.13 \pm 0.05$ for $E_s(\rho_0) = 31.6$ MeV. C_1 and C_2 are fixed from the mass dependent symmetry coefficient of finite nuclei (say ^{208}Pb).

Results and Discussion

In Fig.2, we have shown the behaviour of $E_s(\rho)$ as considered in this work for three values of γ within its fitted limits. In the figure, we have also shown the density dependence of $E_s(\rho)$ for a parametrized form $E_s(\rho) = E_s(\rho_0)u^{0.69}$ and that of Dong et al. [3] for comparison. One can note that at suprasaturation densities, our proposed form becomes softer compared to the other two forms. We have calculated the symmetry slope parameter and curvature parameter respectively from the new relation as $L = 50.8, 50.4, 49.9$ MeV and $K_{sym} = -126, -132, -138$ MeV corresponding to $\gamma = 1.08, 1.13, 1.18$. These values are well within the range as predicted from different calculations.

Conclusion

We have investigated the density dependence of nuclear symmetry energy using a parametrized from. The parameters of the proposed relation have been fixed from a correlation between the symmetry slope parameter and curvature parameter calculated from some well known Skyrme type interactions. The predicted values of these parameters from the proposed form of $E_s(\rho)$ lie well within the range predicted earlier.

References

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