Symmetry energy coefficient in the mass formula

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The study of nuclear symmetry energy $E_{sym}(\rho)$ which essentially characterizes the isospin dependent part of the equation of state of asymmetric nuclear matter is now-a-days an exciting topic of research in nuclear physics. Based on the calculations within the droplet model and mean field models using a number of different parameter sets, Centelles et al [1] found that the symmetry energy coefficient $a_{sym}(A)$ of finite nuclei with mass number A in the semi-empirical mass formula can be approximately equal to the symmetry energy $E_{sym}(\rho)$ of nuclear matter at a reference density ρ_A in the subnormal density region i.e. $E_{sym}(\rho_A) \approx a_{sym}(A)$ (1)

This relation helps us to determine the symmetry energy at sub-normal densities from the semi-empirical mass formula directly and also has many important implications for extracting the symmetry energy from isospin dependent observables of finite nuclei [1]. Using semi-empirical mass formula the mass dependence of symmetry energy coefficient $a_{sym}(A)$ of finite nuclei can be expressed as [1]

$$a_{sym}(A) = E_{sym}(\rho_0)\,[1 + x_A A^{-1/3}]^{-1}\,, \qquad (2)$$

with $x_A = 9E_{sym}(\rho_0)/4Q$. Here Q is so-called neutron-skin stiffness coefficient in the droplet model and it measures the resistance of the nucleus against separation of neutrons from protons to form a neutron skin. Q can be obtained from semi-infinite nuclear matter calculation. Using a density dependent finite range effective interaction [2] between pairs of like and unlike nucleons x_A can be obtained for all splitting of $E_{ex}^{\,l}$ and $E_{ex}^{\,ul}$ [3] and are listed in Table I. Further it is found that for these values of x_A the relation $E_{sym}(\rho_A) = a_{sym}(A)$ is valid for a reference density ρ_A. This result is in consistent with the result proposed by Centelles et al in ref. [1]. It is observed that the value of reference density does not change with the change in $E_{ex}^{\,l}$ for a particular mass number of finite nuclei. According to the recent research in intermediate energy heavy ion collision (HIC) the density dependent nuclear symmetry energy at subnormal densities [4] can be written as,

$$E_{sym}(\rho) = E_{sym}(\rho_0)\left(\frac{\rho}{\rho_0}\right)^{\alpha} \qquad (3)$$

From Eq. (1), (2) and (3) the reference density ρ_A for a nucleus with mass number A can be expressed as

$$\rho_A = \frac{\rho_0}{\left(1 + x_A A^{-1/3}\right)^{1/\alpha}}\,. \qquad (4)$$

From Eq. (4) the reference density is plotted as a function of nuclear mass A for various values of $E_{ex}^{\,l}$ in Fig: 1 and the result is also compared with the parameterized expression $\rho_A = \rho_0 - \rho_0/\left(1 + c\,A^{1/3}\right)$ proposed by Centelles et. al. [1]. It is found from the graph that the reference densities for finite nuclei with A=20–250 lies within the range $0.4\rho_0 \le \rho_A \le 0.63\rho_0$ for different values of $E_{ex}^{\,l}$ using Eq. (4) as well as for the relation proposed in ref. [1]. It is further observed that the reference densities obtained from different splitting of $E_{ex}^{\,l}$ as well as the result proposed by Centelles [1] are in good agreement with each other. Centelles et al. tested the parameterization of above expression for mass region $40 \le A \le 208$ [1]. For mass region A < 40 and A > 208 all the results shows similar extrapolation. It can also be noted from Fig:1 that for heavy nuclei the reference densities change slowly with the mass number and reaches to 0.1 fm^{-3} whereas for light nuclei the reference density falls rapidly with the decrease of mass number. So the symmetry energy of nuclear matter at reference density is more appreciably related to the symmetry energy of heavy nuclei than that of the lighter nuclei. The density dependence of symmetry energy at sub-saturation density is plotted in Fig: 2 for different values of $E_{ex}^{\,l}$. In the same Fig. the result obtained from the relation [4] is also shown for the sake of comparison, which agrees very well with the result obtained for $E_{ex}^{\,l} = 4E_{ex}/3$. Two vertical parallel lines in the graph correspond to the density range $0.4\rho_0 \le \rho_A \le 0.63\rho_0$ of nuclei with mass number A=20 – 250.

Table I: Values of reference density ρ_A and $E_{sym}(\rho_A)$ for different values of $E_{ex}^{\,l}$.

Values of E_{ex}^{l}	ρ_{208} fm^{-3}	$E_{sym}(\rho_{208})$ MeV	x_A (MeV)	α
$E_{ex}/3$	0.104	24.34	1.678	0.52
$2E_{ex}/3$	0.104	23.13	1.9	0.58
$4E_{ex}/3$	0.104	21.21	2.34	0.7
$5E_{ex}/3$	0.104	20.44	2.56	0.75

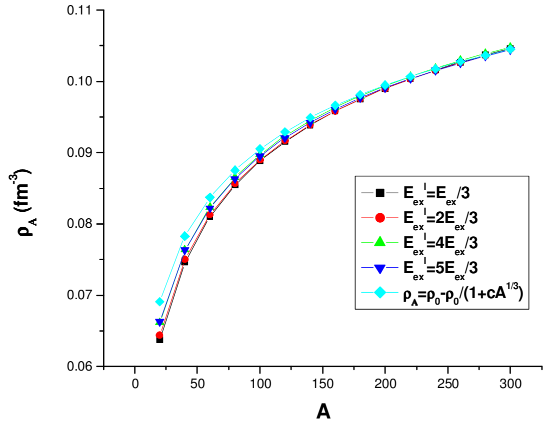

Fig: (1)

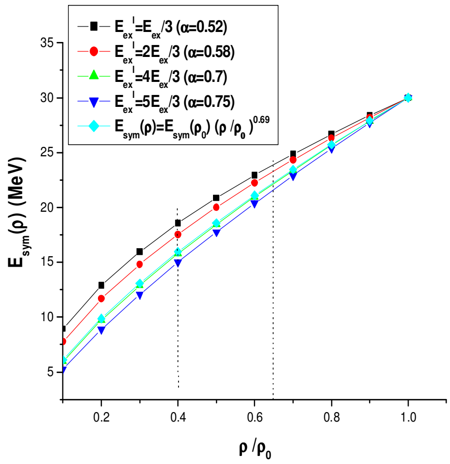

Fig: (2)

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