Symmetry energy coefficient from an extended mass formula

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Recently the symmetry energy of finite nuclei has been investigated by fitting ground state masses in the liquid drop mass formula to get information on the density dependence of symmetry energy. On the basis of the constraints obtained from the different studies of nuclear matter symmetry energy, Centelles et al. [1] found that symmetry energy coefficient $a_{sym}(A)$ of finite nuclei with mass number A in the semi empirical mass formula can approximately equal to nuclear matter symmetry energy at reference density ρ_A in the sub saturation density region i.e. $E_{sym}(\rho_A) = a_{sym}(A)$. Using the semi-empirical mass formula the mass dependence of symmetry energy coefficient $a_{sym}(A)$ of finite nuclei can be expressed as [1]:

$$a_{sym}(A) = \frac{E_{sym}(\rho_0)}{1 + x_A}, \qquad (1)$$

with $x_A = \dfrac{9E_{sym}(\rho_0)}{4Q} A^{-1/3}$,

where $E_{sym}(\rho_0)$ is the symmetry energy at saturation density ρ_0. The Q parameter is the so-called neutron-skin stiff-ness coefficient in the droplet model [2, 3] and it is related to the nuclear surface symmetry energy [4, 5]. Usually for a given nuclear interaction, the Q parameter can be obtained from asymmetric semi-infinite nuclear matter calculations [6].

The symmetry energy coefficient $a_{sym}(A)$ plotted as a function of mass number (A) (with 20<A<170) for different sets of exchange strength parameters of $E_{ex}{}^{l}$ and $E_{ex}{}^{ul}$ [7,8] given as $E_{ex}{}^{l} = \frac{E_{ex}}{2}$ (for setA1) and $E_{ex}{}^{ul} = \frac{E_{ex}}{2}$ (for set A2) in Fig:1 . It is observed that when $E_{ex}{}^{l}$ is greater than $E_{ex}{}^{ul}$ the value of $a_{sym}(A)$ lies within 25-28 MeV and when $E_{ex}{}^{ul}$ is greater than $E_{ex}{}^{l}$ it lies within 19-24 MeV for 20<A<170.

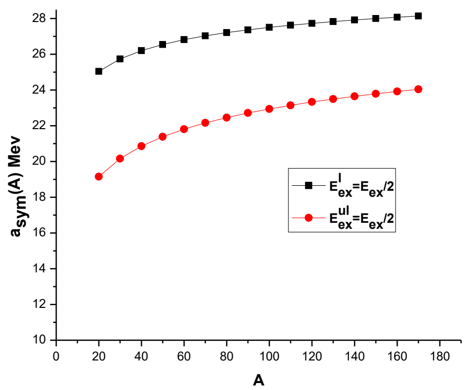

Fig.1: plot of $a_{sym}(A)$ against A considering saturation density for two sets of interactions.

Now if we extend the mass formula by considering the correction due to the variation of central density ρ_{cen} in finite nuclei and assume the radius R as [9]:

$$R = r_0(1+3\chi_{cen})^{-1/3}A^{-1/3} \qquad (2)$$

where $\frac{4}{3}\pi\rho_0 r_0^{\,3} = 1$ and $\chi_{cen} = (\frac{\rho_{cen}-\rho_0}{3\rho_0})$ is a dimensionless variable characterising the deviation of the central density ρ_{cen} of finite nuclei from the saturation density ρ_0. With this consideration the symmetry energy coefficient $a_{sym}(A)$ can be expressed as [9]

$$a_{sym}(A) = D_2(A)\left[E_{sym}(\rho_0) + a_c Z^2 \chi_2 A^{-\frac{4}{3}} + \left(\frac{E_{sym}{}^2(\rho_0)}{\beta} - 2E_{s0}\chi_2 A^{-\frac{1}{3}}\right)\right] \qquad (3)$$

where $D_2(A) = \frac{1}{\left(1+\frac{E_{sym}(\rho_0)}{\beta}A^{-\frac{1}{3}}\right)}$ is the fraction of volume neutron excess, $\beta = \frac{\sigma_1}{4\pi r_0^{\,2}}$ and $E_{s0} = 4\pi r_0^{\,2}\sigma_0$, $\sigma_0(\sigma_1)$ represents isospin independent (dependent) surface tension. $\chi_2 = -\frac{L}{K_0}$ .In eq. (3) a small Z dependent term $a_c Z^2 \chi_2 A^{-\frac{4}{3}} D_2$ comes from the modification of ρ_{cen} due to the coulomb energy. For negligible contribution it can be neglected and the above eq. can be written as

$$a_{sym}(A) = D_2(A)\left[E_{sym}(\rho_0) + \left(\frac{E_{sym}{}^2(\rho_0)}{\beta} - 2E_{s0}\chi_2 A^{-\frac{1}{3}}\right)\right]$$

Now again $a_{sym}(A)$ is plotted against A for the same range 20<A<170 in Fig.2. It is observed that when $E_{ex}{}^{l}$ is greater than $E_{ex}{}^{ul}$ the value of $a_{sym}(A)$ lies within 17.5-22.8 MeV and when $E_{ex}{}^{ul}$ is greater than $E_{ex}{}^{l}$ it lies within 18-23 MeV for 20<A<170. Thus it can be concluded that considering the central density, a consistent value of $a_{sym}(A)$ can be obtained for both the splitting of $E_{ex}{}^{ul}$ and thus it plays an important role to calculate the symmetry energy coefficient as well as neutron skin thickness.

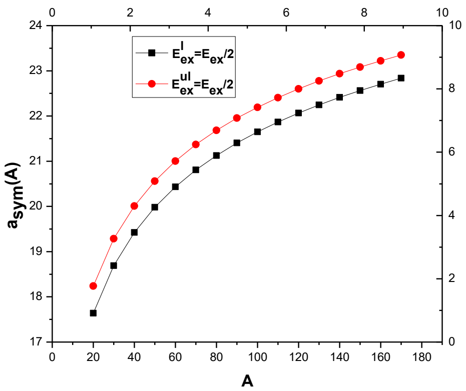

Fig. 2: plot of $a_{sym}(A)$ against A considering the central density for the two sets of interactions.

References

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