A study of neutron skin thickness in different models

S. Chakraborty[1], M. Pal[2], B. Sahoo[3] and S. Sahoo[4]*
[1]Department of Physics, M. M. M. College, Durgapur, West Bengal, India.

[2]Department of Physics,S. M. H. Govt. College for Women, Kulberia, West Bengal, India

[3]Department of Physics, T.D.B. College,Raniganj, West Bengal, India.

[4]Department of Physics, National Institute of Technology, Durgapur, West Bengal, India.

*E-mail: sukadevsahoo@yahoo.com

The neutron skin thickness (NST) of a nucleus is conventionally defined as the difference between the neutron and proton r. m. s radii of the nucleus.

$$S = \sqrt{r_n^2} - \sqrt{r_p^2} \qquad (1)$$

The calibration of the neutron skin thickness of nuclei is one of the problems at the forefront of nuclear structure by reason of being infinitely correlated with the nuclear symmetry energy. Indeed, the symmetry energy is a fundamental quantity in nuclear physics and astrophysics, because it governs at the same time important properties of very small entities like atomic nuclei and of very large objects like neutron stars. In literature there exist several theoretical formulations to investigate the neutron skin thickness of neutron rich nuclei and its connection with symmetry energy. It has been shown that the neutron skin thickness in heavy nuclei like ^{208}Pb , calculated in mean-field models with either non-relativistic or relativistic effective interactions, displays a linear co-relation with the slope (L) of the symmetry energy at saturation. The droplet model (DM) describes a physically transparent correlation between NST (S) and L [1]. In the present article, we study the neutron skin thickness of atomic nuclei with DM using a finite range effective interaction [2]. Within the DM, the NST of a nucleus is given by

$$S = \sqrt{\frac{3}{5}}\left[t - \frac{e^2 z}{70\,E_{sym}\left(\rho_0\right)} + \frac{5}{2R}\left(b_n^2 - b_p^2\right)\right], \qquad (2)$$

where $\frac{e^2 z}{70\,E_{sym}\left(\rho_0\right)}$ is correction due to the coulomb interaction and $R = r_0 A^{1/3}$ is the nuclear radius and bn and bp are the surface width of the neutron and proton density profile. In the standard version of droplet model it is assumed that bn = bp = 1 fm [1], which implies a vanishing surface width correction to the neutron skin thickness. The quantity 't' in the above expression represents the distance between the neutron and proton mean surface location which is given by

$$t = \frac{3r_0}{2}\frac{E_{sym}(\rho_0)/Q}{1 + x_A A^{-1/3}}\left(I - I_C\right), \qquad (3)$$

where $I = \frac{N-Z}{A}$ and $I_C = \frac{e^2 z}{20\,E_{sym}(\rho_0)R}$ is correction due to coulomb interaction. The surface stiffness Q measures the resistance of the nucleus against separation of neutrons from protons to form a neutron skin. Using equation

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

and

$x_A = 9E_{sym}\left(\rho_0\right)/4Q$ in equation (3) the value of 't' becomes

$$t = \frac{2r_0}{3E_{sym}(\rho_0)}\left[E_{sym}(\rho_0) - a_{sym}(A)\right]A^{1/3}\left(I - I_C\right) \qquad (4)$$

The NST (S) is plotted as a function of slope (L) for different sets of exchange strength parameters E_{ex}^{l} and E_{ex}^{ul} for a finite range effective interaction of Yukawa form given in ref[3] considering A1) $E_{ex}{}^{l} = \frac{E_{ex}}{3}$ and A2) $E_{ex}{}^{ul} = \frac{E_{ex}}{3}$ in Fig: 1. In the same fig ‘S’ is plotted against ‘L’ for experimental result given in [1] for the sake of comparison.

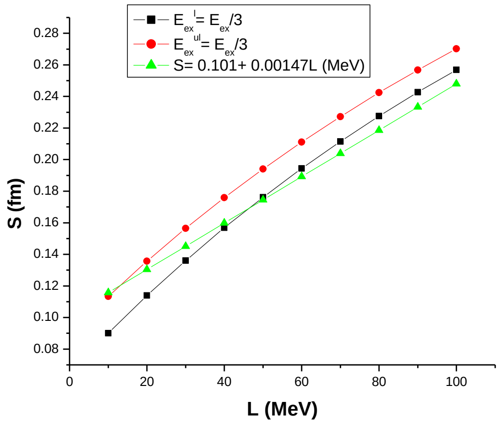

fig.1: S is plotted as a function of L for sets A1 ,A2 and for S = 0.101+0.00147 L (MeV)

The fig shows that NST ‘S’ varies linearly with the slope ‘L’, which is consistent with the experimental results. Further it is also observed that the experimental curve agrees well with the result obtained from $E_{ex}{}^{l} = \frac{E_{ex}}{3}$ for the slope 40-60 MeV for which the NST lies within 0.15-0.19 fm.

Again, the NST of different stable nuclei (40 ≤ A ≤ 238) was extracted from experiments. The data roughly follow a linear trend with the relative neutron excess I of the nucleus [1]. The NST (S) predicted by DM with bn = bp is plotted as a function of ‘I’ for different sets of exchange strength parameters $E_{ex}{}^{l}$ and $E_{ex}{}^{ul}$ [3] in Fig: 2. In the same fig ‘S’ is plotted against ‘I’ for experimental result given in [1] for the sake of comparison. The results nicely reproduce the average trend of the experimental data.

The Lead Radius Experiment (PREX) [4] has recently measured the neutron skin thickness $S = 0.33^{+0.16}_{-0.18}$ fm [4]. The analyses from recent hadronic experiments have led to varying values of the neutron skin thickness of ^{208}Pb, $S = 0.211^{+0.054}_{-0.063}$ fm [5].

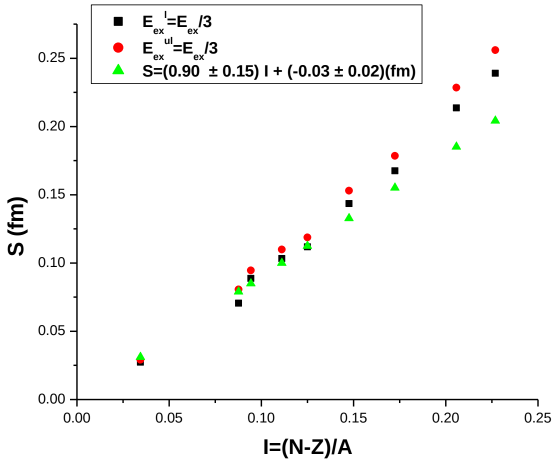

Fig.2. ‘S’ is plotted as a function of $I = \frac{N-Z}{A}$ for parameter sets A1 and A2 and for S=(0.90 ± 0.15) I + (-0.03 ± 0.02)fm.

A very recent measurement of coherent pion photo production provides a value S = 0.15 ± 0.03 fm for ^{208}Pb [5].

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