# A Study of Neutron Skin Thickness in Neutron Rich Nuclei within Skyrme-Hartree-Fock-Bogoliubov Formalism

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## Introduction

The basic property of the nuclei is the distribution of the nucleon density. In nuclear many particle system, the distribution of quantum states of proton and neutron provide the stability to atomic nuclei. To determine the nature of the neutron distribution accurately in a nuclei has received considerable attention in recent years. It is well established that In light nuclei with N $\simeq$ Z, the nucleons have similar density distributions. For middle weight and heavy nuclei, the bulk of neutron density is believed to extend beyond the proton density creating a sort of "neutron skin". We present our theoretical results of neutron skin thickness $\Delta r_{np}$ for neutron-rich nuclei. The $\Delta r_{np}$ in $^{48}$Ca, $^{68}$Ni, $^{120,132}$Sn and $^{208}$Pb nuclei has been calculated. The theoretically computed results with UNEDF0 parameterization of functional are reasonably reproducing the observed data for $\Delta r_{np}$ in $^{48}$Ca, $^{68}$Ni and $^{120,132}$Sn. New energy density UNEDF1 provides much improved result of $\Delta r_{np}$ for $^{208}$Pb.

## Theoretical Framework

We employed self-consistent mean field models analogous to Kohn-Sham density functional theory to construct the Skyrme Energy Density Functionals [1] from Hartree-Fock-Bogoliubov Hamiltonian based on single-particle wave functions of the transformed harmonic oscillator with zero-range pairing interactions. For Skyrme forces, the HFB energy has the form of a local energy density functional:

$$E[\rho, \tilde{\rho}] = \int d^3r \mathcal{H}(r) \tag{1}$$

where

$$\mathcal{H}(r) = H(r) + \tilde{H}(r) \tag{2}$$

is the sum of the mean-field and paring energy densities. This leads to the HFB Hamiltonian matrix

$$\begin{pmatrix} h^{(q_k)} - \lambda^{(q_k)} & \tilde{h}^{(q_k)} \\ \tilde{h}^{(q_k)} & -h^{(q_k)} + \lambda^{(q_k)} \end{pmatrix} \begin{pmatrix} U_k \\ V_k \end{pmatrix} = E_k \begin{pmatrix} U_k \\ V_k \end{pmatrix} \tag{3}$$

where the quasiparticle energies $E_k$, the chemical potential $\lambda^{q_k}$, and the matrices

$$h^{(q)}_{\alpha\beta} = \langle \Phi_\alpha | h_q | \Phi_\beta \rangle, \qquad \tilde{h}^{(q)}_{\alpha\beta} = \langle \Phi_\alpha | \tilde{h}_q | \Phi_\beta \rangle \tag{4}$$

are defined for a given proton ($q_k = +1/2$) or neutron = ($q_k = -1/2$) block.

## Result and Discussion

The neutron skin thickness $\Delta r_{np}$ is defined as the difference between the nuclear rms radii obtained using the density distributions for point neutrons and point protons; $\Delta r_{np} = \sqrt{r_n^2} - \sqrt{r_p^2}$, where $r_n$ signifies the neutron rms radius and $r_p$ denotes the proton rms radius. We present our theoretical results of neutron skin thickness for neutron-rich nuclear systems $^{48}$Ca, $^{68}$Ni, $^{120}$Sn, $^{132}$Sn and $^{208}$Pb. The computed results are compared to the recently available experimental data. The computed

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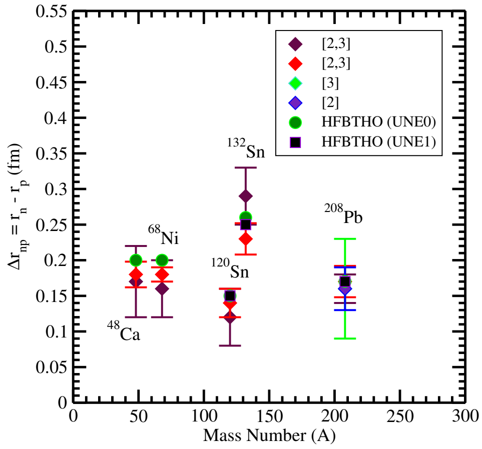


FIG. 1: (color online) The neutron skin thickness $\Delta r_{np} = r_n - r_p$ in fm, plotted as a function of nuclear mass number A.

data and experimental results of $\Delta r_{np}$ for neutron exotic nuclei $^{68}$Ni are also presented as shown in FIG. 1, and compared with its recent experimental/theoretical observations.

There are many theoretical and experimental investigations focused on $^{208}Pb$, $^{132}Sn$, $^{120}Sn$, $^{68}Ni$ and $^{48}Ca$ nuclei, which have well understood nuclear structure due to their closed protons and neutrons shells at the magic numbers. A recent reviews on experimental measurements of $\Delta r_{np}$ in $^{208}Pb$, suggest that its values ranges from 0.15±0.03 fm [3] to 0.22±0.04 fm [3], with the analysis of coherent pion photo-production and pion scattering, respectively. Whereas our theoretical results for $\Delta r_{np} = 0.17$ fm in $^{208}Pb$ are reasonable well within the experimental measurements.

In FIG. 1, we have also presented and compared our results of $\Delta r_{np}$ for $^{132}Sn$, $^{120}Sn$, $^{68}Ni$ and $^{48}Ca$ nuclei. It can be seen clearly that the theoretically estimates from HFBTHO model (with both UNE0 and UNE1 parameterizations) are nicely matching with the recently available experimental data. UNE0 parameterization are giving very good results of neutron skin thickness while UNE1 parameterization are producing even better results of skin thickness for the doubly magic nuclei with higher mass number as we can see in the FIG. 1. For lower mass number range , the result of UNE0 parameterization is overestimated by approximately 0.03 fm (when compared with experimental data [2]) and almost matching (when compared with experimental data [2]) for $^{48}$Ca. Also for $^{68}$Ni, our result calculated with UNE1 parameterization is overestimated by approximately 0.09 fm and 0.1 fm (when both result are compared with the experimental data taken from [2]. For nuclei having number of protons and number of neutrons both magic numbers i.e. 2, 8, 20, 28, 50, 82 and 126 has extra stability and results in high binding energy than the neighbouring nuclides in periodic table. The results that we have computed here are taken from Axially deformed solution of the Skyrme-Hartree-Fock-Bogoliubov equations using the transformed harmonic oscillator model (HFBTHO) based on Energy Density Functional (EDF) parameterizations UNE0 and UNE1.

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