Study of even-even Lead (Pb) isotopes based on Covariant Density Functional Theory

Virender Thakur,* Raj Kumar,† Pankaj Kumar, and Shashi K Dhiman‡
Department of Physics, Himachal Pradesh University, Summer-Hill, Shimla-171005, INDIA

Introduction

Nuclear many body system is very complex system and effective theoretical model is needed for reliable predictions in the nuclear structure systems. The production of the new isotopes [1] in recent years has revived a great interest in nuclear structure models. Neutron rich nuclides are very important systems [2] as the asymmetry between the proton and the neutron number increases in these systems and leads to the phenomena like neutron skin and halos. We have chosen Lead(Pb) nuclei from the periodic table as a representative of the heavy mass range systems for our theoretical study. Lead nucleus is very important system and it has important implications in the nuclear structure systems due to the magicity of proton number (Z) present in it and various experimental nuclear sturucture properties related to double magicity are available in literature [3, 4]. The isotopic chain under our theoretical investigation ranges from mass number A=182 to mass number A=214 for the Lead(Pb) nucleus. The theoretical model is based on the CDFT. The nuclear ground state observables like charge radii, root mean square radius and neutron skin thickness reflecting the size of the nucleus are studied and compared with available experimental data.

Theoretical model

This presented work is carried out with the Covariant Relativistic Hartee Bogoliubov (RHB) Theory [5] and the details of theoretical framework is also presented in our previous work [6].

*Electronic address: virenthakur2154@gmail.com
†Electronic address: raj.phy@gmail.com
‡Electronic address: shashi.dhiman@gmail.com

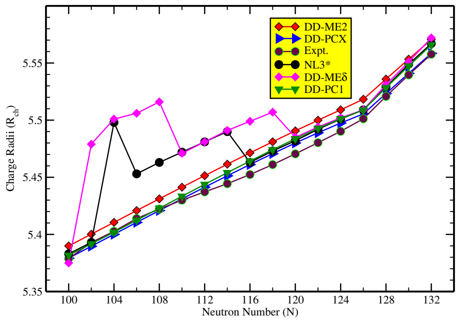

FIG. 1: (color online) Theoretical results of Root mean square charge radii (R_{ch}) compared with the availabe experimental data [7].

Result and Discussion

Nuclear charge radii (R_{ch}) and Root mean square radius (R_{rms}) are the key nuclear structure ground state observables that determine the size of the nuclear system. In addition to this, Neutron skin thickness (Δr_{np}) is also very important observable which reflects the stability of the nucleus. The theoretical results for R_{ch},R_{rms} and Δr_{np} are shown in the Fig. (1 ,2 and3) respectively.

The results for the nuclear charge radii R_{ch} in units of fermi meter (fm) are plotted against the neutron number (N) for the isotopic chain of Lead(Pb) nuclides ranging from mass number A=182 to A= 214 as shown in Fig. (1). The theoretical charge radius is calculated using the formulae [8] :

$$R_{ch} = \sqrt{r_p^2 + 0.64} \;\; fm \tag{1}$$

Here, r_p denotes the rms radius of the proton density distribution and term 0.64 fm^2 accounts for the finite size of proton. Experimental results are also shown for comparison taken from ref. [7] and it can be

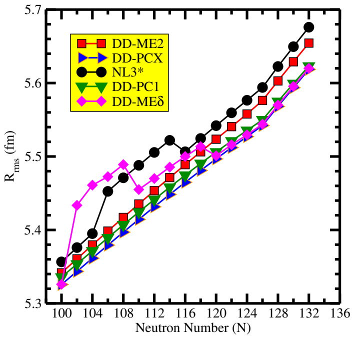

FIG. 2: (color online) Root mean square radii (R_{rms}) plotted against neutron number (N) for even-even $^{182-214}$Pb isotopes.

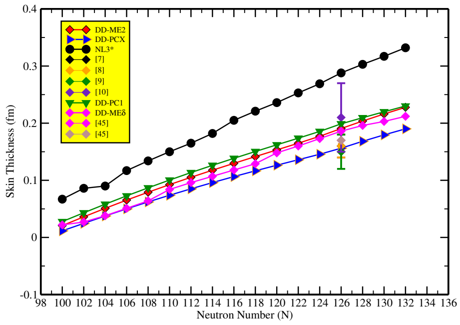

FIG. 3: (color online) Neutron skin thicknes (Δr_{np}) plotted against neutron number (N) for even-even $^{182-214}$Pb isotopes.

seen easily that our results are in fairly good agreement with the experimental findings. Results calculated with NL3* and DD-MEδ parameterisations[9, 10] are also shown for comparison. Similar trend as shown in Fig. (1) is repeated in Fig. (2) representing the results for root mean square radius of the nuclei which is the average of proton and neutron radii. There is gradual increase in the values R_{rms} with the neutron number. Trend is attributed to redistribution of the nucleons inside the nuclei to overcome the coulomb repulsion by the addition of excess of the neutron. It is also clear from the Fig. (1), that our results calculated with DD-ME2, DD-PC1 and DD-PCX parameterisations are following the trend as per the experimental findings.

Fig. (3) represents our results for the neutron skin thickness (Δr_{np}). The neutron skin thickness Δr_{np} is defined as

$$\Delta r_{np} = \sqrt{r_n^2} - \sqrt{r_p^2}, \tag{2}$$

It can be seen easily in Fig. (3), that there is gradual increase in the neutron skin thickness with the increase in the neutron number along the isotopic chain of the $^{182-214}$Pb nuclei. Gradual increase in the neutron skin thickness indicates that as the neutron number is increased, the nucleons adjust themselves in such a way so that the maximum stability is acquired and further increase along higher mass region is attributed to the fact of less bound neutrons giving rise to higher value of neutron skin as shown in Fig. (3).

Acknowledgments

Virender Thakur is highly thankful to Himachal Pradesh University and DST-INSPIRE for providing computational facility and financial assistance (Junior Research Fellowship).

References

[1] Virender et al. Thakur. *Acta Physica Polonica B*, 53(2), 2022.
[2] MM Sharma and P Ring. *Physical Review C*, 45(5):2514, 1992.
[3] E. Friedman. *Nuclear Physics A*, **896**:46 – 52, 2012.
[4] C. M. et al. Tarbert. *Phys. Rev. Lett.*, **112**:242502, Jun 2014.
[5] T Nikšić, Dario Vretenar, and Peter Ring. *Progress in Particle and Nuclear Physics*, 66(3):519–548, 2011.
[6] Virender et al. Thakur. *Nuclear Physics A*, 1002:121981, 2020.
[7] István Angeli and Krassimira Petrova Marinova. *Atomic Data and Nuclear Data Tables*, 99(1):69–95, 2013.
[8] T. Niksic, N. Paar, D. Vretenar, and P. Ring. *Computer Physics Communications*, **185**(6):1808–1821, 2014.
[9] SE Agbemava, AV Afanasjev, D Ray, and P Ring. *Physical Review C*, 89(5):054320, 2014.
[10] http://massexplorer.frib.msu.edu.