J. Nucl. Phys. Mat. Sci. Rad. A. Vol. 9, No. 2 (2022), pp.187–191

CHITKARA

Journal of Nuclear Physics, Material Sciences, Radiation and Applications

Journal homepage: https://jnp.chitkara.edu.in/

Charge Radius And Neutron Skin Thickness Of Platinum And Osmium Isotopes Near The Nuclear Drip Lines

Anjana A V[*], **Nicemon Thomas** and **Antony Joseph**

Department of Physics, University of Calicut, Kerala-673635, India

[*]anjanasayoojyam88@gmail.com (Corresponding Author)

ARTICLE INFORMATION

Received: January 28, 2022
Revised: May 30, 2022
Published Online: June 20, 2022

Keywords:
HFB theory, Nuclear drip lines, Charge radii, Skyrme functional, Neutron skin thickness

DOI: 10.15415/jnp.2022.92027

ABSTRACT

Background: The density distributions of exotic nuclei are different from that of stable nuclei. For stable nuclei, charge radii can be obtained through electron scattering experiments. The excessive neutrons in neutron-rich nuclei make a decoupling of neutron and proton distribution and as a result nuclear skin structures are appeared.

Purpose: The charge radius and the way by which nucleons are distributed can provide information about size, surface thickness and shell structure of nuclei. The information collected from such nuclei can be used for astrophysical studies to understand the origin of heavy elements.

Methods: In the present study, we have made an attempt to investigate the charge radii, rms radii and skin thickness of Pt and Os isotopes. Here, the calculations were made by using the HFB solver which utilizes HO single-particle basis and iteratively diagonalizes the HFB Hamiltonian based on the Skyrme forces.

Results: Here we can observe an increase in charge radius, rms radius and skin thickness with increase in neutron number. The charge radii calculated are in good agreement with the experimental data and predictions of RCHB model. A linear dependence of the skin thickness on neutron number is observed and a change in the value is noticed around N =126.

Conclusion: Using HFB theory, we have analyzed the charge radius and neutron skin thickness of Pt and Os isotopes. The drip line nuclei have larger charge radius in comparison to the stable nuclei. The redistribution of the nucleons due to addition of neutrons leads to the gradual increase in neutron skin. The sudden increase of skin thickness may be due to the extra stability and shell closure around the magic number.

1. Introduction

With the availability of energetic radioactive ion beams, the nuclear structure studies [1] have achieved considerable progress in recent years. The distribution of the nucleon density is one of the basic properties of a nucleus. In nuclear many particle systems, the distribution of quantum states of proton and neutron provide the stability to the atomic nucleus. The nucleons have similar density distributions in light nuclei with N=Z [2]. The density distributions of exotic nuclei [3] near the nuclear drip lines are very different from that of the stable nuclei. The neutron density profile extend beyond the proton density profile, as the excessive neutrons are pushed out against the nuclear surface and thereby creating a sort of neutron skin. The neutron-rich nuclei are the class of exotic nuclei having large values of N/Z ratio. Self consistent mean field theory is one of the most important theories, which helps in understanding medium and heavy mass nuclei. In mean-field estimations [4], the neutron skin thickness is identified with the divergence in the Fermi energies among neutrons and protons.

In a given nucleus, the pairing energy is not constant for a constant pairing gap Δ [5], since it depends on the deformation parameter and the occupation probabilities near the Fermi surface. The way in which nucleons are distributed in the nucleus and the charge radius provide information on the basic properties of nuclei, such as surface thickness, size and shell structure. For stable nuclei, charge radii can be obtained through the electron scattering experiment [6]. The nuclear charge radius is one of the most important nuclear properties that depict the effect of effective interactions on nuclear structure. The charge radii can be analysed to understand the size of the given isotopes.

The excessive neutrons in neutron-rich nuclei produce a divergence in the Fermi energies among neutrons and protons, which in turn make a decoupling of neutron and

ISSN No.: 2321-8649(Print) ISSN No.: 2321-9289(Online); Registration No. : CHAENG/2013/51628

proton distributions and leads to the appearance of nuclear halo and skin structures [7]. Neutron skin thickness is the difference in matter radii for neutrons and protons whereas halo is the low density tails in nuclear matter distribution. In finite nuclei and infinite nuclear matter, neutron skin plays an essential role in correlation with a number of physical observables [8]. Skin thickness is associated with the restrictions imposed on the equation of state of high density nuclear matter in neutron stars. The information collected from such nuclei can be used for astrophysical studies to understand the origin of heavy elements.

2. Theoretical Formalism

In the present work, we have made an attempt to investigate the charge radii (R_c), neutron root mean square (rms) radii (R_n), proton rms radii (R_p) [9] and neutron skin thickness of Platinum and Osmium isotopes. Here we have performed a numerical analysis by Hartree-Fock-Bogoliubov (HFB) calculations [10], with Universal Nuclear Energy Density Skyrme Functional (UNEDF0). The calculations were made by using the HFB solver, which utilizes Harmonic Oscillator (HO) single-particle basis and iteratively diagonalizes the Hartree-Fock-Bogoliubov (HFB) Hamiltonian (h) [11], based on the Skyrme forces, until the self-consistent solution is achieved. The HFB theory consider the mean field part and pairing part [12] with equal importance.

In the matrix form, the HFB equation is given by,

$$\begin{pmatrix} (h-\lambda) & \Delta \\ -\Delta & -(h-\lambda) \end{pmatrix} \begin{pmatrix} U_n \\ V_n \end{pmatrix} = E_n \begin{pmatrix} U_n \\ V_n \end{pmatrix} \quad (1)$$

where E_n is the quasiparticle energy and λ is the chemical potential.

The HFB equations are solved using the axially deformed HO [13] basis. In the pairing part we have employed the density dependent delta interaction (DDDI) [14,15] and in the mean field part the zero range Skyrme interaction.

The pairing channel was parametrized by DDDI in its mixed form and is given by,

$$V_{pair}^{(n,p)} = V_0^{(n,p)}\left(1-\eta\frac{\rho_0(r)}{\rho_c}\right) \quad (2)$$

where $V_0^{(n,p)}$ is the pairing strength for protons and neutrons, $\rho_0(r)$ is the isoscalar local density and ρ_c is the saturation density [16]. By adjusting the value of η, the density dependence of the pairing interaction could be varied. Here η = 1 corresponds to the surface interaction, having pure density dependence and η= 0 corresponds to the volume interaction, having no density dependence. η = 0.5 corresponds to mixed pairing with average effects of both surface and volume interactions.

The nuclear charge radii R_c are obtained by folding the proton distribution with the finite size of proton and neutron. The charge radius is calculated by using the formula,

$$R_c = \sqrt{R_p^2 + 0.64} \quad (3)$$

where R_p denotes the rms radius of proton density distribution.

In heavy nuclei, the number of neutrons are found to be more as compared to the number of protons, which lead to the formation of neutron skin on its surface [17]. The neutron skin thickness ΔR_{np} is given by,

$$\Delta R_{np} = R_n - R_p \quad (4)$$

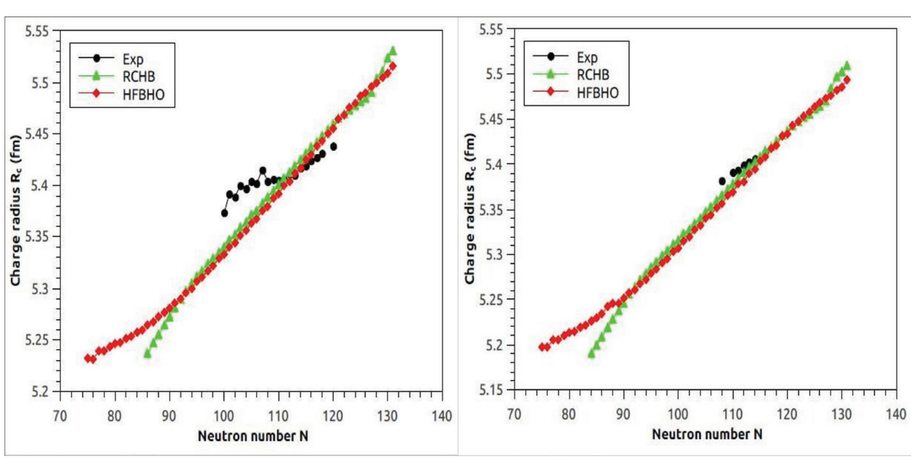

Figure 1: Variation of charge radius with neutron number of Platinum (left) and Osmium (right) isotopes.

Taking Platinum and Osmium isotopes as examples, we performed a numerical analysis by self-consistent Skyrme HFB calculations with UNEDF0 parametrizations [18]. Here, we present our theoretical results for charge radii, neutron rms radii, proton rms radii and neutron skin thickness, in even-even and even-odd isotopes [19] of Pt and Os. In an earlier work, Nithu et al. carried out some calculations on even-even Pt and Os isotopes by using different Skyrme forces [20]. In the present study, we further focus on charge radius, rms radius and neutron skin thickness of even-even and even-odd nuclei of Platinum and Osmium isotopes and their comparison with available theoretical and experimental data. The presence of odd mass nuclei breaks the time reversal symmetry and so the theoretical calculations are difficult for them. In the case of odd isotopes, the computations were made by blocking the quasi-particle states to take care of the time reversal symmetry in the mean-field model. In this case, an approximation to the exact blocking called Equal Filling Approximation (EFA) [21] is used.

3. Results and Discussion

In order to interpret the skin structure and the size of the considered isotopic series of Platinum and Osmium, charge radii, neutron rms radii, proton rms radii and neutron skin thickness [17, 22] were calculated within the HFB theory, from β-stable to the neutron drip line region and are plotted in figures, which follows. The charge radius R_c for the ground states of the whole isotopic chain is determined and the obtained results are shown in Figure 1. In this work, we present the calculated results for nuclear charge radius as a function of neutron number N, in even-even and even-odd isotopes of Pt and Os nuclei, by employing HFB model with UNEDF0 Skyrme parametrizations. The computed results agree reasonably well with the results from Relativistic Continum Hartree-Bogoliubov (RCHB) theories [23] and the available experimental data [6]. From Figure 1, it is clear that the charge radius is smaller for stable isotopes, when compared to that for the isotopes lying near to the neutron drip line regions. The abrupt increase in R_c may lead to changes in the shape of the isotopes. The calculated theoretical values of charge radius for these isotopes agree well with the available experimental data.

For predicting the feasible skin structure of Platinum and Osmium isotopes, we have calculated the rms radii and neutron skin thickness. The calculations were done using the HFB theory from the proton rich region to the neutron rich region, near to the nuclear drip lines and the results are plotted in Figures 2 and 3. The neutron rms radii (R_n) and proton rms radii (R_p) determined are plotted against the neutron number for Pt and Os, as given in Figure 2. From this figure, we notice that the values of rms radii increases with neutron number. The sharp increase in the value of neutron rms radii at the drip line regions indicates the larger neutron radius and appearance of skin structure. We compared the computed results with the data available from RCHB theories for the given nuclides and we can see that the computed results from HFBHO model are matching almost well with the available data. The results that we have computed here are obtained from axially deformed solution of the Skyrme-Hartree-Fock-Bogoliubov equations based on the Energy Density Functional (EDF) parametrization UNEDF0, using the harmonic oscillator model.

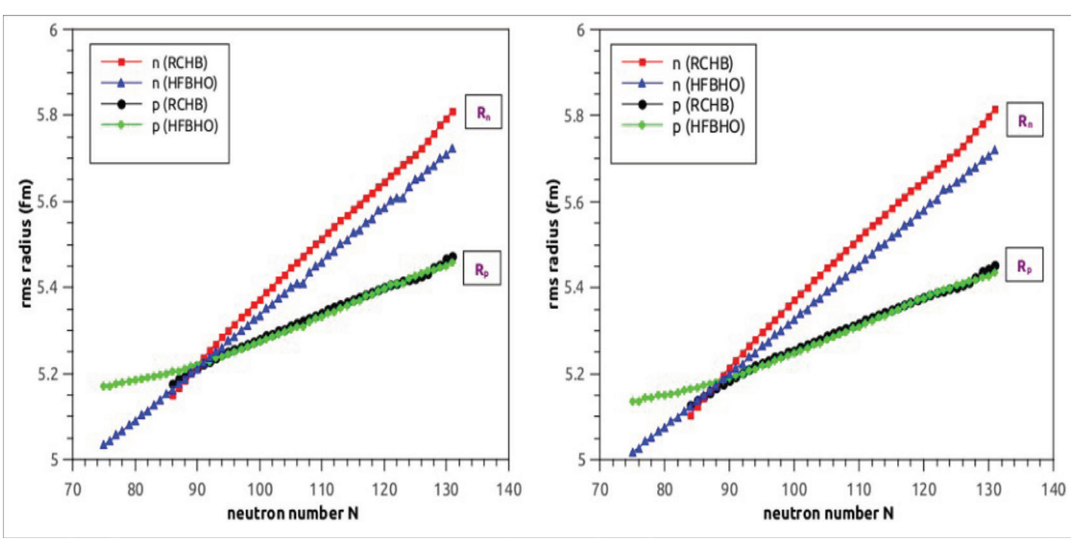

Figure 2: Variation of rms radius with neutron number of Platinum (left) and Osmium (right) isotopes.

The neutron skin is the significant difference in the values of matter radii for neutrons and protons and it describes the excess of neutrons at the nuclear surface. In Figure 3, we have presented and compared our results of the neutron skin thickness ΔR_{np} as a function of neutron number N for the considered isotopic chains of Pt and Os. In the case of the isotopes selected for the present study, the magnitude of skin thickness increases systematically with the number of neutrons. The skin in nuclei arises due to a very weak binding of the last one or two valence nucleons and hence get decoupled from the rest of nucleons in the nucleus. The magnitude of skin thickness increases gradually with increase in the neutron number for the given isotopes. The redistribution of the nucleons due to addition of neutrons leads to the gradual increase in the neutron skin. The neutron rich nuclei show the skin thickness of the order of 0.3 fm. A linear dependence of the neutron skin thickness on mass number exist, as can be seen from Figure 3 and a sudden increase of the neutron skin thickness (kink) is noticed around N =126. To simulate the symmetry energy for the neutron-rich matter, the predicted neutron skin for exotic nuclei can be used. This type of kink in the skin plot indicates unexpected behaviour of the nuclei and supposed to be halo/skin structure candidates.

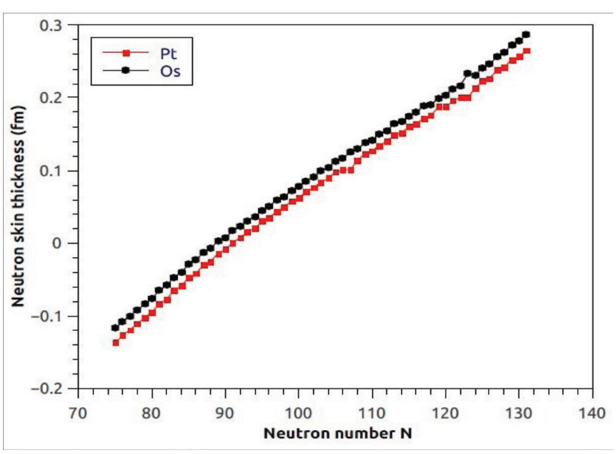

Figure 3: Variation of neutron skin thickness with neutron number of Platinum and Osmium isotopes.

4. Conclusion

By using the HFB theory, we have explored the charge radii, proton radii, neutron radii, and neutron skin thickness over a series of the isotopic chains of Platinum and Osmium. The charge radii calculated within the framework of the HFB theory by using the Skyrme functional UNEDF0 are compared with the available experimental data and with the predictions of RCHB model. Good agreement between theory and experiment can be clearly seen in Figure 1. Here, we can observe an increase in charge radius R_c with increase in neutron number for all nuclei. It is clear from the figure that, those nuclei which lie in the neutron drip line have larger charge radius in comparison to the stable nuclei. Also, we have estimated the neutron skin thickness from neutron and proton rms radii for exotic nuclei of Pt and Os. To understand the skin structure, proton and neutron rms radii were plotted as a function of neutron number and compared with available data. The rms radii and neutron skin thickness are increasing with neutron number. Neutron skin thickness increases linearly with neutron number and a sudden change in this trend is noticed around N=126. This sudden increase of neutron skin thickness may be due to the extra stability and shell closure around the magic number.

Acknowledgements

One of the authors, Anjana A V expresses the gratitude to Council of Scientific and Industrial Research (CSIR), Govt. of India, New Delhi, for the grant under Junior Research Fellowship (JRF) scheme (reference No:09/043(0214)/2019-EMR-I dated 05/03/2020).

Authorship contribution

Anjana A V: Conceptualization, data analysis and interpretation, review, editing & visualization; Nicemon Thomas: Validation; Antony Joseph: Overall supervision.

Funding

No separate funding has been received for the research work mentioned in this manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest among the authors.

Declarations

The research work presented here is not published partially or in total, anywhere else, by me or someone else. It is my original work.

References

[1] J. Dobaczewski and W. Nazarewicz, Philos. Trans. R. Soc. London A, **356**, 2007 (1998). https://doi.org/10.1098/rsta.1998.0261

[2] S. Frauendorf, and A. O. Macchiavelli, Progress in Particle and Nuclear Physics, **78**, 24 (2014). https://doi.org/10.1016/j.ppnp.2014.07.001

[3] R. F. Casten and B. M. Sherrill, Prog. Part. Nucl. Phys., **45**, S171 (2000). https://doi.org/10.1016/S0146-6410(00)90013-9

[4] J. Dobaczewski, W. Nazarewicz and M.V. Stoitsov, Eur. Phys. J. A, **15**, 21 (2002). https://doi.org/10.1140/epja/i2001-10218-8

[5] A. Bohr, B. R. Mottelson and D. Pines, Phys. Rev **110**, 936 (1958). https://doi.org/10.1103/PhysRev.110.936

[6] I. Angeli, K. P. Marinova, At Data Nucl. Data Tables **90**, 69 (2013). https://doi.org/10.1016/j.adt.2011.12.006

[7] N. Schunck and J. L. Edigo, Phys. Rev. C, **78**, 064305 (2008). https://doi.org/10.1103/PhysRevC.78.064305

[8] M. M. Sharma and P. Ring, Phys. Rev. C, **45**, 2514 (1992). https://doi.org/10.1103/PhysRevC.45.2514

[9] R. J. Furnstahl, Nucl. Phys. A, **706**, 85 (2002). https://doi.org/10.1016/S0375-9474(02)00867-9

[10] J. Suhonen, From Nucleons to Nucleus : Concepts of Microscopic Nuclear Theory, Springer (2007).

[11] P. Ring and P. Shuck, The Nuclear Many-Body Problem, Springer, Berlin (1980).

[12] S. A. Changizi, C. Qi, and R. Wyss, Nuclear Physics A, **940**, 210 (2015). https://doi.org/10.1016/j.nuclphysa.2015.04.010

[13] M. V. Stoitsov *et al.,* Computer Physics Communications, **167**, 43 (2005). https://doi.org/10.1016/j.cpc.2005.01.001

[14] R.R. Chasman, Phys. Rev. C, **14**, 1935 (1976). https://doi.org/10.1103/PhysRevC.14.1935

[15] J. Terasaki, P. H. Heenen, P. Bonche, J. Dobaczewski and H. Flocard, Nucl. Phys. A, **593**, 1 (1995). https://doi.org/10.1016/0375-9474(95)00316-S

[16] J. Terasaki, H. Flocard, P. H. Heenen and P. Bonche, Nucl. Phys. A, **621**, 706 (1997). https://doi.org/10.1016/S0375-9474(97)00183-8

[17] S. Mizutori, J. Dobaczewski, G. A. Lalazissis, W. Nazarewicz, and P.-G. Reinhard, Phys. Rev. C, **61**, 044326 (2000). https://doi.org/10.1103/PhysRevC.61.044326

[18] M. Kortelainen et al., Phys. Rev. C, **82**, 024313 (2010). https://doi.org/10.1103/PhysRevC.82.024313

[19] M. Bhuyan *et al.*, International Journal of Modern Physics E, **24**, No.4, 1550028 (2015). https://doi.org/10.1142/S0218301315500287

[20] N. Ashok and A. Joseph, Int. J. Mod. Phy. E, **27**, No.10, 1950093 (2019). https://doi.org/10.1142/S0218301319500939

[21] M. V. Stoitsov *et al.*, Computer Physics Communications, **184**, 1592 (2013). https://doi.org/10.1016/j.cpc.2013.01.013

[22] J. Dobaczewski, W. Nazarewicz and T. R. Werner, Z. Phys. A, **354**, 27 (1996). https://doi.org/10.1007/S002180050009

[23] X. W. Xia *et al.,* At. Data and Nucl. Data Tables, **121**, 1 (2018). https://doi.org/10.1016/j.adt.2017.09.001

CHITKARA

Journal of Nuclear Physics, Material Sciences, Radiation and Applications

Chitkara University, Saraswati Kendra, SCO 160-161, Sector 9-C, Chandigarh, 160009, India

Volume 9, Issue 2	**February 2022**	**ISSN 2321-8649**