Exotic behaviour analysis in the “Rutherfordium" Isotopic Chain

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Introduction:

Here effort is made for theoretical prediction of shell and sub-shell closures in even-even isotopes of the first transactinide element Rutherfordium (Z=104) with mass range 234 < A < 334. Ground state characteristics such as binding energy (B.E.) and rms radii are estimated using the PK1 parameter [1] underneath relativistic mean field theory (RMF) [2], using initial deformations [3] such as -0.35, -0.2, -0.1, 0, 0.1, 0.2, and 0.35, in order to provide a readily apparent comprehension of nuclear structure. Two neutron separation energy (S_{2n}), two neutron differential (dS_{2n}), and neutron skin thickness (R_{np}) are calculated using the estimated B.E. and isotopic shifts are observed in the continuous trend.

Theoretical Formulation:

Relativistic Mean Field Theory (RMF)

The Lagrangian density is

$$\mathscr{L} = \bar{\psi}_i(i\gamma_\mu \partial_\mu - M)\psi_i + \frac{1}{2}\partial^\mu\sigma\partial_\mu\sigma - \frac{1}{2}m_\sigma^2\partial^2 - \frac{1}{3}g_2\partial^3 - \frac{1}{4}g_3\partial^4 - g_5\bar{\psi}_i\psi_i\sigma - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_\omega^2 V^\mu V_\mu + \frac{1}{4}C_3(V_\mu V^\mu)^2 - g_\omega\bar{\psi}_i\gamma^\mu\psi_i V_\mu - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} + \frac{1}{2}m_\rho^2\vec{R}^\mu . \vec{R}_\mu - g_\mu\bar{\psi}_i\gamma^\mu\vec{\tau}\psi_i\vec{R}^\mu - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\bar{\psi}_i\gamma^\mu\frac{(1-\tau_{3i})}{2}\psi_i A_\mu \quad \text{.................(1)}$$

The symbols have their usual meaning. On solving the field equations derived from it , we get ground state properties such as the binding energies (B.E.), rms values of nuclear radii, of nucleus etc. With the B.E values we estimate the following quantities [4].

$$S_{2n}(N,Z) = B.E.(N,Z) - B.E.(N-2,Z) \quad ..(2)$$

$$dS_{2n} = S_{2n}(N,Z) - S_{2n}(N+2,Z) \quad \text{............(3)}$$

Neutron skin thickness $(R_{np})=R_n-R_p$… …(4)

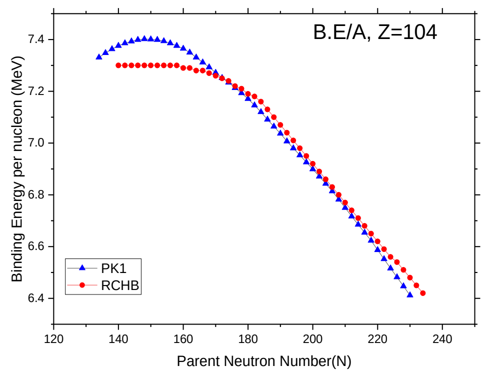


Fig.-1. The binding energy per nucleon (B.E./A) with RMF (PK1) are compared with RCHB [6] for Rf isotopes.

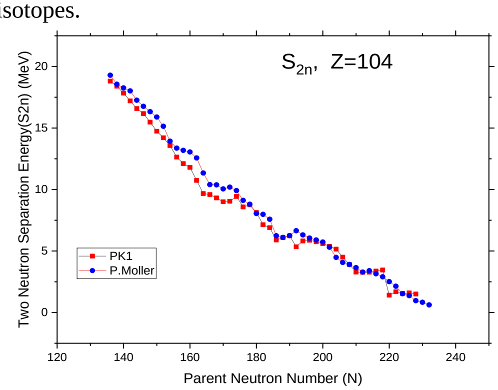


Fig.-2. The Two neutron separation energy with RMF (PK1) are compared with P.Moller [7] results for Rf isotopes.

Results and Discussions:

Stability is better decided by B.E./A. One can see from Fig. 1 that the value is greatest for N = 148 as previously anticipated [5]. RCHB facts are used to compare B.E./A values [6]. The PK1 parameter in RMF Theory is utilised to compute two neutron separation energies (S_{2n}) for even-even isotopes $^{234-334}$Rf based on the binding energies. The shell and sub-shell closures have been crucially predicted by S_{2n} for isotopes $^{234-334}$Rf by using PK1 parameter in RMF Theory. More perspicuous study of S_{2n} is in Fig.-2 and compared with the results of P.Moller [7]. Two neutron differential of S_{2n} (dS_{2n}) is shown in Fig.-3, and is connected to surface phenomena of heavy and super heavy nuclei [8]. In Fig.2 isotopic shift occurs at N=136,154,174,178,192,212,218,220 and it is better matching with Ref. [7].

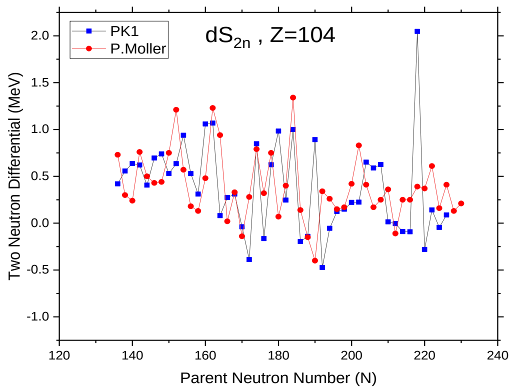
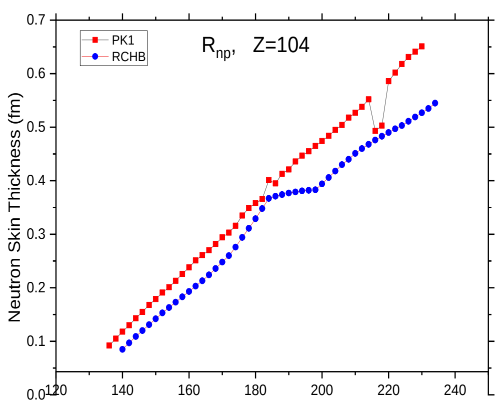


Fig.-3. The two neutron differential energy (dS_{2n}) with RMF (PK1) are compared with the results of P.Moller [7] for Rf isotopes.



. Fig.-4. The neutron skin thickness (r_{np}) from RMF (PK1) are compared with RCHB [6] values for Rf isotopes.

We see strong isotopic changes at and near N=162,184,192,218,220 in Fig.-3, indicating stability and agreeing with P. Moller results Ref. [7] as well as earlier studies [9]. The graph exhibits variability near N=162, 184, 192, and 218 that suggests a phase change [10]. Two isotope shifts are seen at N=184 and N=218 in Fig. 4. This indicates the shell or sub-shell closures. Referring back to Fig. 4, it indicates the fluctuation of neutron skin thickness with neutron number. In an isotopic chain, testing the shell closures is most crucial.

Conclusion:

We used the PK1 parameter in the RMF model to predict the B.E. of even-even isotopes of $^{234-334}$Rf. Using B.E.s and r_{np}, we have computed S_{2n} and dS_{2n}. The current analysis concludes, more specifically, that for each of the $^{234-334}$Rf isotopes, the bulk characteristics result in a shell/sub-shell closure at N=136, 154, 162, 178, 184, 192, 212, 218, and 220.

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