Comprehensive Analysis of "Rf" Element Carbon Decay

G.Tripathy[1,2]*, , P. Mohanty[1], A. Anupam[1], C. Dash[3] , K. K. Jena[4], B. B Sahu[1*]

[1] *School of Applied Sciences, KIIT Deemed to be University, Bhubaneswar 751024, India*

[2]*Department of physics, Nayagarh Autonomous College ,Nayagarh. 752069, Odisha ,India*

[3]*Department of Physics, Maharaja Sriram Chandra Bhanja Deo University, Baripada-757003, India*

[4]*P. G. Department of Physics, Bhadrak Autonomous College, Bhadrak-756100, Odisha, India.*

* *Email: tripathygitanjali21@gmail.com; bbsahufpy@kiit.ac.in*

Introduction:

Cluster decay of ^{12}C and ^{14}C are comprehensively analyzed to investigate the shell/sub-shell closure of $^{240-340}$Rf nuclei from the corresponding decay half-lives. We have estimated the ground state properties of even-even isotopes of Rutherfordium (Z=104) using PK1[1] parameter within relativistic mean field theory (RMF) [2.] Furthermore, the calculation of energy released during the decay of ^{12}C and ^{14}C the estimation of decay half-lives are performed using binding energy (B.E.). This is achieved through the effective use of UDL-1[3], UDL-2[4], Unified Formula[5], and Santosh's semi-empirical formula[6].

A long half-life of parent predicts parent's stability and a small half-life of parent predicts the of daughter's stability against decay.

Theoretical Formulation:
Relativistic Mean Field Theory (RMF)

The Lagrangian density is [7-11]

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

The symbols have their usual meaning. The ground state properties of nuclei like binding energy are obtained by solving the Lagrangian density. Corresponding 'Q' values are calculated for ^{12}C and ^{14}C decay, from Which $T_{1/2}^{C12}$ *and* $T_{1/2}^{C14}$ are estimated.

Energy Released during cluster decay

$Q_{cluster}$ (Z, N) = E_{bind} (daughter) + E_{bind}(cluster) - E_{bind}(parent)

Universal Decay Law - 2 (UDL)

$$Log_{10}T_{1/2}\ (s) = a\ z_c\ z_d\sqrt{\frac{A}{Q_c}} + b\sqrt{A\, z_c\, z_d\, (A_c^{\frac{1}{3}} + A_d^{\frac{1}{3}})} + c \quad \ldots\ldots\ldots\ldots\ldots(2)$$

, Here A = $\frac{A_c\, A_d}{(A_c + A_d\,)}$ is the reduced mass of emitted cluster- daughter nucleur system. a=0.4314, b= -0.3921, c= -32.7 [4]. Another set of parameters are also available for the same formulae known as UDL-1 [3] where a=0.40796, b=-0.42253, c= -21.58684.

Unified Formula

$$Log_{10}T_{1/2}\ (s) = a\ \sqrt{A}\ \ z_c\ \ z_d Q_c^{-1/2} + b\ \sqrt{A}\ (z_c\, z_d)^{1/2} + c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where a=0.38617, b= -1.08676, c_{e-e}= -21.37195 are the parameters. z_c and z_d are atomic numbers of cluster and daughter nucleus respectively [5].

Santhosh's Semi-Empirical Model

$$Log_{10}T_{1/2}\ (s) = a\ z_c\ z_d Q_c^{-1/2} + b\eta_A + c \quad \ldots\ldots(4)$$

Where $\eta_A = \frac{A_d - A_c}{A}$ is the mass asymmetry [6]. The values of adjustable parameters are a= 0.727356, b= 40.3887 and c= -85.1625 respectivelly. z_c and z_d are atomic numbers of cluster and daughter respectively.

Results and discussions:

From the figure-1, it is clear that for ^{12}C at N=188, Q-value is maximum. In fig-2 $T_{1/2}^{C12}$ is maximum at N=218, 228 and minimum at N=188 which confirms parent Rutherfordium shell is stabilized at N= 218,228 and daughter Californium is stabilized at N=182 (as 188-6).

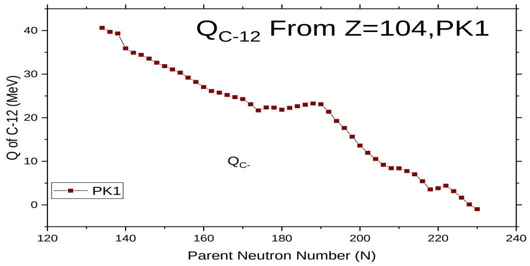

Fig.1 Predicted values of energy released during Carbon -12 from even-even isotopes of Z=104

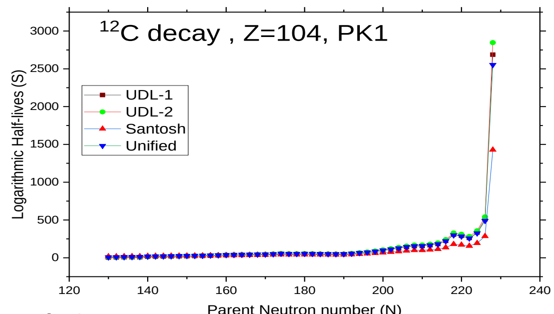

Fig-2 Variation of Log $T_{1/2}$ of C^{12} decay from even-even isotopes of $^{240-340}$Rf with parent Neutron number (N) using PK1 parameter in RMF Formalism

In figure-3 for ^{14}C at N=192 Q-value is maximum, In fig-4, $T_{1/2}^{C14}$ is maximum at N=176, 220 and minimum at N=192 which confirms that parent Rutherfordium shell is stabilized at N=176, 220 and daughter Californium is stabilized at N=184 (as 192-8). So it again Proves that N=184 is the most stable isotope .

Conclusion:

The B.E. of even-even isotopes of $^{240-340}$Rf (Z=104) was computed using the PK1 parameter in the RMF model. We employ distinct formulae to compute the energy released during the decay of ^{12}C and ^{14}C with the objective to determine their respective half-lives. Our results show that the shells at N=182, 218, and 228 are stable against ^{12}C decay and against ^{14}C decay, respectively, at N=176, 184, and 228.

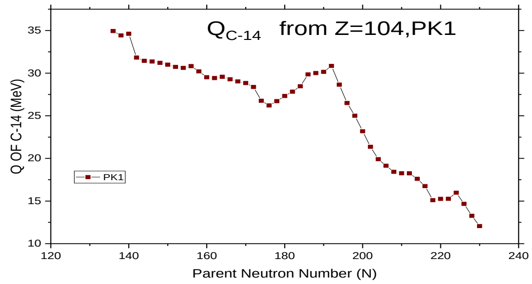

Fig-3 Predicted values of energy released during carbon -14 decay from even-even isotopes of Z=104

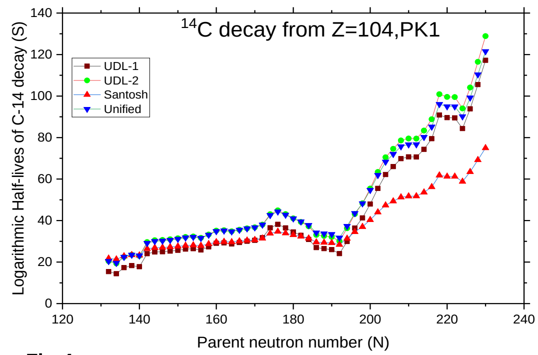

Fig-4 Variation of Log$T_{1/2}$ of C^{14} decay from even even isotopes of $^{240-340}$Rf as a function of parent neutron number (N) by using PK1 parameter in RMF formalis

References:

[1] P.W.Zhao, Z.P.Li, J.M.Yao and J.Meng, Phys. Rev. C 82,054319 (2010) American Physical Society.

[2] L. I. Schiff, Phys. Rev., 84: 1 (1951)

[3]] Dashty T,etal10.1142/S0218301319500757

[4] R. Kumar and M. K. Sharma, Phys. Rev. C 85, 054612 (2012).

[5] M. Balasubramaniam and N. S. Rajeswari, Int. J. Mod. Phys. E 23, 1450018 (2014).

[6] K. P. Santhosh, R. K. Biju, and A. Joseph, J. Phys. G: Nucl.Part. Phys. 35, 085102 (2008).

[7] R.R. Swain, *et al*., Int. Journal of Modern Phys. E 28, 1950041 (2019).

[8] G. Tripathy, B.B. Sahu *et al.,* AIP Conf. Proc. 3122, 050004 (2024)

[9] G.Tripathy ,B.B.Sahu *et al*., Proceedings of the DAE Symp. on Nucl. Phys. 66,186 (2022).

[10]] G. Tripathy, B.B. Sahu *et al.,* AIP Conf. Proc. 2901, 040022 (2023)

[11] G. Tripathy, B.B. Sahu *et al*., Proceedings of the DAE Symp. On Nucl. Phys. 67, 177-178 (2023)