α-radioactivity in odd-A superheavy nuclei (SHN) for Z= 118-120

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1. Introduction

SHN research, both theoretical and experimental, have emerged as one of the main topics of nuclear physics research in recent years [1]. The SHN are highly unstable and can break via various decays viz. α-decay, spontaneous fission, cluster decay, etc. The decay statistics show that α emission is the predominant decay mode for SHN [2].

This study investigates the α-decay half-lives of unknown odd-A SHN for $Z = 118 - 120$. The calculations are carried out for the preformation probability (P_α) of α particle inside α-emitter for $Z = 103 - 117$ nuclei using a microscopic phenomenological approach incorporating the energy density functional (EDF) of the Skyrme force within the WKB approximation. P_α for unsynthesized SHN are estimated using the $N_P N_N \cdot I$-scheme, which then are used to estimate their α-decay half-lives. Moreover, the calculated half-lives are also compared with other theoretical models such as the universal decay law (UDL), and generalized liquid drop model(GLDM).

2. Theoretical framework

Alpha-decay half-life of an α-radioactive nucleus can be calculated as:

$$T_{1/2} = \frac{\ln 2}{P_\alpha \left(\frac{1}{2} \int_0^{\frac{\pi}{2}} \nu(\theta) P(\theta) \ \sin\theta \ d\theta \right)}. \quad (1)$$

Here, "θ" is the orientation angle of the emitted α particle to the symmetric axis of the deformed daughter nucleus. The penetrability ($P(\theta)$) and the assault frequency $\nu(\theta)$ of the α particle are given as:

$$P(\theta) = \exp\left(-\frac{2}{\hbar} \int_{a'(\theta)}^{b'(\theta)} \sqrt{2\mu(V(r,\theta) - Q_\alpha)} \ \ dr \right) \quad (2)$$

$$\nu(\theta) \sim \frac{(G + \frac{3}{2})\hbar}{1.2\pi\mu R_p(\theta)^2} \quad (3)$$

Here, G is the global quantum number, Q_α is the α-disintegration energy, $a'(\theta)$ & $b'(\theta)$ are classical turning points. μ is the reduced mass of α-particle and the daughter nucleus, also $R_{d,p}(\theta) = R_0 \left(1 + \beta_2^{d,p} Y_{20}(\theta) + \beta_4^{d,p} Y_{40}(\theta)\right)$ fm where $R_0 = 1.18 \ A_{d,p}^{1/3}$. The total two-body interaction potential is given as $V(r,\theta) = V_C(r,\theta) + V_N(r,\theta) + \frac{\hbar^2}{2\mu r^2}\left(l + \frac{1}{2}\right)^2$. l is the orbital angular momentum. To incorporate $V_N(r,\theta)$ in eq.(2), we have utilized the EDF of the Skyrme force to consider the interaction of the point-like α particle with the nucleons of the core of decaying nucleus [3] :

$$\begin{aligned} V_N(r,\theta) &= \alpha\rho_N(r,\theta) + \beta(\rho_n^{5/3}(r,\theta) + \rho_p^{5/3}(r,\theta)) \\ &+ \gamma\rho_N\epsilon(r,\theta)(\rho_N^2(r,\theta) + 2\rho_n(r,\theta)\rho_p(r,\theta)) \\ &+ \delta\frac{\rho_N{}'(r,\theta)}{r} + \eta\rho_N{}''(r,\theta) \quad (4) \end{aligned}$$

$\rho_{n,p,N}$ are the density profiles of nucleons ($\rho_N = \rho_n + \rho_p$), and $V_C(r,\theta)$ is given as : $V_C(r,\theta) = \frac{Z_d Z_\alpha e^2}{r}\left(1 + \frac{3R_0^2}{5r^2}\beta_2^d Y_{20}(\theta) + \frac{3R_0^4}{9r^4}\beta_4^d Y_{40}(\theta)\right)$

3. Results and Discussion

Utilizing Q_α and experimental $T_{1/2}$-values from [4] in eq. 1, the P_α's are calculated for odd-A SHN. The obtained P_α's are subjected to $N_P N_N \cdot I$-scheme, leading to a linear equation written as:

$\log_{10} P_\alpha = a\frac{N_P N_N}{N_0+Z_0} \cdot I + b$ where $N_P = Z - Z_0, N_N = N - N_0$ are valance protons

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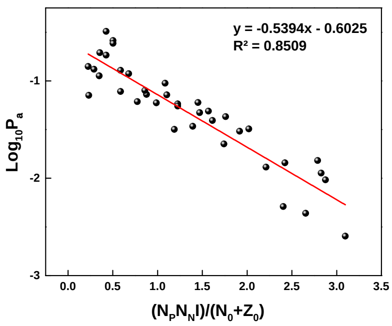

FIG. 1: $\log_{10} P_\alpha$ values for odd-A SHN are plotted w.r.t. $\frac{N_P N_N}{N_0+Z_0} \cdot I$ and a linear fit is demonstrated here as well.

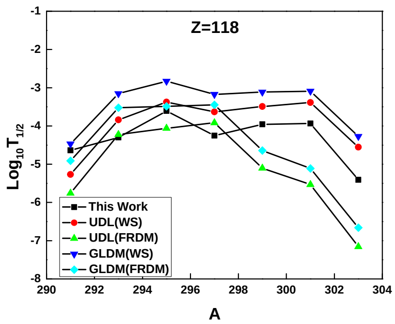

FIG. 2: Comparison of calculated α-decay half-lives ($\log_{10} T_{1/2}$(sec)) with other theoretical findings for $Z = 118$.

and neutrons, respectively and I is the isospin of parent nuclei. Using the $N_P N_N \cdot$ I-scheme, a straight line fit with $R^2 \sim 0.8509$ is obtained, as shown in Fig. 1. The fitted equation described in fig. 1 is then used to calculate P_α values for unknown SHN with $Z = 118 - 120$. Incorporating these P_α values into eq. 1, the α-decay half-lives ($T_{1/2}$(sec)) for unknown odd-A nuclei are determined. Theoretical half-life predictions indicate that the alpha-decay half-life timescales for these nuclei fall within the microsecond range, making them experimentally detectable.

In figs. 2 and 3 we have compared the logarithmic values of calculated α decay half-lives (seconds) of Z=118, 119, and 120 with the UDL formula and GLDM with Q_α from Weizsäcker-Skyrme (WS) and the finite range droplet model (FRDM) [5].

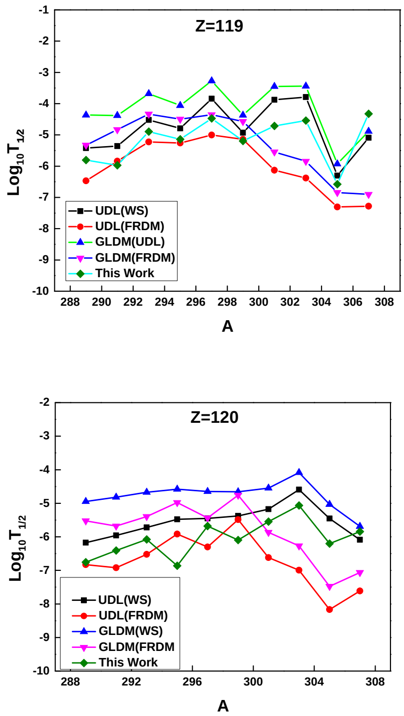

FIG. 3: Comparison of calculated α-decay half-lives ($\log_{10} T_{1/2}$ (sec)) with other theoretical findings for Z= 118 and 119.

Using proposed methodology the α decay half-lives of unknown odd-A SHN are successfully predicted. This work provides a valuable framework for scientists focused on synthesizing new SHN and island of stability.

References

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