α-decay chains of superheavy nuclei with $Z = 125$

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The decay properties of the isotopes of $Z = 125$ within the range $303 \leqslant A \leqslant 339$ are investigated. The calculation of proton separation energies reveals that isotopes $^{303-309}125$ may decay through proton emission. Four different mass tables are used to show the sensitivity of the mass models used to calculate the Q values as well as the α-decay half-lives. α-decay chains are predicted by comparing the α half-lives calculated within the Coulomb and proximity potential model for deformed nuclei (CPPMDN) [Nucl. Phys. A **850**, 34 (2011)] with the spontaneous fission half-lives using the shell-effect-dependent formula [Phys. Rev. C **94**, 054621 (2016)]. It is seen that isotopes $^{310,311}125$ show 6α chains. 5α chains can be seen from isotopes $^{312-318}125$. Isotopes $^{319,320}125$ exhibit 2α chains and $^{323}125$ exhibits 1α chain. All the other isotopes, that is, $^{321,322,324-339}125$ may decay through spontaneous fission. The α half-lives using CPPMDN are compared with five other theoretical formalisms and are seen to be matching with each other. We hope that our studies will be helpful in designing future experiments to explore the island of stability.

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I. INTRODUCTION

The prediction of the magic island or the island of stability [1–5] in the late 1960s paved the way for the theoretical as well as experimental studies of superheavy nuclei (SHN). The superheavy elements refer to the elements far beyond uranium with atomic number $Z > 104$. The synthesis of SHE are mainly performed with two fusion evaporation approaches: the cold fusion reaction [6] and the hot fusion reaction [7]. Elements with $Z = 107-113$ [8–10] were produced at GSI, Darmstadt and RIKEN, Japan using cold fusion reaction and elements up to $Z = 118$ were synthesized at JINR-FLNR, Dubna with hot fusion reactions [11]. Attempts to synthesize isotopes with $Z = 120$ are also being done using these fusion evaporation approaches [12,13].

The early studies on SHN were based on the macroscopic-microscopic (MM) models [14–16] which make use of various liquid drop models as well as single particle shell models. The macroscopic-microscopic model in which the macroscopic part is treated by the continuous medium model and the microscopic part consists of shell and pairing corrections based on the Nilsson potential was used by Peng *et al.* [17] and by using this model the authors have evaluated the α-decay energies of 323 heavy nuclei with $Z \geqslant 82$. Self-consistent Hatree-Fock-Bogoliubov (SHFB) [18–20] and relativistic mean field (RMF) [21] models are also used for studying the properties of SHN. A review of self-consistent mean field models for nuclear structure can be seen in Ref. [22]. According to MM models the magic number after the presently known $Z = 82$ and $N = 126$ are $Z = 114$ and $N = 184$ [16,23,24]. But the SHF models predict $Z = 120$ or $Z = 126$ and $N = 184$ [25,26] as magic numbers.

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Theoretical studies on SHN give great importance for the predictions on the decay properties of SHN. This is because all the heaviest known isotopes were identified from their decay chain. The main decay modes of SHN are α decay and the spontaneous fission (SF). Many of the known SHN exhibit sequential α-decay chains which follow subsequent SF. So the models and formalisms used to describe the α-decay [27–31] and SF [32–36] properties play a significant role in designing experiments in the superheavy region.

In order to reach the shore of the island, a number of theoretical studies [37–43] are being performed at and around the predicted magic numbers. Our group had previously studied the decay properties of even Z superheavy elements within the range $104 \leqslant Z \leqslant 136$ [44]. We had also done studies on the decay properties of elements with $Z = 121$ [45] and $Z = 123$ [46]. The present paper deals with the studies on the α decay and SF of the superheavy element with $Z = 125$. We hope that our study will also be a part of the dream of reaching the magic island.

The paper is arranged as follows. In Sec. II a detailed description of the model, that is, the Coulomb and proximity potential model for deformed nuclei (CPPMDN) [47], used for studying the α decay is given. Section III deals with the results and discussions obtained from the study, and Sec. IV gives the summary of the entire work.

II. MODEL: THE COULOMB AND PROXIMITY POTENTIAL MODEL FOR DEFORMED NUCLEI (CPPMDN)

In CPPMDN the interacting potential between two nuclei is taken as the sum of the deformed Coulomb potential, the deformed two term proximity potential, and the centrifugal potential, for both the touching configuration and the separated

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TABLE I. One-proton and two-proton separation energies for the isotopes of $Z = 125$, which may decay through proton emission.

Isotope	$S(p)$ (MeV)	$S(2p)$ (MeV)
$^{303}125$	−1.801	−1.542
$^{304}125$	−1.491	−1.342
$^{305}125$	−0.751	−1.102
$^{306}125$	−0.801	−1.112
$^{307}125$	−0.831	−0.842
$^{308}125$	−1.701	−1.692
$^{309}125$	−1.681	−1.372

fragments. It is given by

$$V = V_C(r,\theta) + V_{P2}(r,\theta) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2}, \quad (1)$$

where $V_c(r,\theta)$ is the Coulomb interaction between the two deformed and oriented nuclei, $V_{P2}(r,\theta)$ is the two-term proximity potential, ℓ represents the angular momentum, and μ is the reduced mass.

The Coulomb interaction between the two deformed and oriented nuclei [48], $V_c(r,\theta)$, with higher multipole deformations [49,50] is given as

$$V_C(r,\theta) = \frac{Z_1 Z_2 e^2}{r} + 3Z_1 Z_2 e^2 \sum_{\lambda=2,3,4;i=1,2} \frac{1}{2\lambda+1} \frac{R_{0i}^{\lambda}}{r^{\lambda+1}} \times Y_{\lambda}^{(0)}(\alpha_i)\left[\beta_{\lambda i} + \frac{4}{7}\beta_{\lambda i}^2 Y_{\lambda}^{(0)}(\alpha_i)\delta_{\lambda,2}\right]. \quad (2)$$

TABLE II. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{310}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T_{1/2}^{\alpha}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{310}125$	11.345[a]	4.390×10^{22}	7.168	7.168	1.157×10^{1}	1.910×10^{-1}	1.346×10^{1}	1.204	α
	15.938[b]		8.144×10^{-10}	8.144×10^{-10}	6.602×10^{-9}	4.544×10^{-10}	1.928×10^{-9}	1.974×10^{-10}	
	16.066[c]		4.950×10^{-10}	4.950×10^{-10}	4.165×10^{-9}	3.014×10^{-10}	1.181×10^{-9}	1.212×10^{-10}	
	14.951[d]		4.653×10^{-8}	4.653×10^{-8}	2.758×10^{-7}	1.313×10^{-8}	1.026×10^{-7}	1.026×10^{-8}	
$^{306}123$	15.165[a]	6.746×10^{14}	8.961×10^{-9}	5.578×10^{-9}	4.229×10^{-8}	2.353×10^{-9}	1.202×10^{-8}	1.280×10^{-9}	α
	14.242[b]		4.855×10^{-7}	3.047×10^{-7}	1.702×10^{-6}	6.810×10^{-8}	6.166×10^{-7}	6.402×10^{-8}	
	14.378[c]		2.635×10^{-7}	1.651×10^{-7}	9.669×10^{-7}	4.054×10^{-8}	3.376×10^{-7}	3.518×10^{-8}	
	13.259[d]		5.241×10^{-5}	3.331×10^{-5}	1.319×10^{-4}	3.835×10^{-6}	6.359×10^{-5}	6.411×10^{-6}	
$^{302}121$	14.055[a]	5.132×10^{11}	2.034×10^{-7}	1.990×10^{-7}	1.238×10^{-6}	5.035×10^{-8}	3.822×10^{-7}	4.178×10^{-8}	α
	13.527[b]		2.425×10^{-6}	2.356×10^{-6}	1.219×10^{-5}	4.158×10^{-7}	4.379×10^{-6}	4.710×10^{-7}	
	13.607[c]		1.651×10^{-6}	1.606×10^{-6}	8.546×10^{-6}	2.992×10^{-7}	2.999×10^{-6}	3.234×10^{-7}	
	12.408[d]		7.600×10^{-4}	7.260×10^{-4}	2.492×10^{-3}	6.070×10^{-5}	1.275×10^{-3}	1.321×10^{-4}	
$^{298}119$	13.085[a]	7.742×10^{8}	7.887×10^{-6}	5.391×10^{-6}	2.807×10^{-5}	9.037×10^{-7}	9.352×10^{-6}	1.049×10^{-6}	α
	12.745[b]		4.401×10^{-5}	3.019×10^{-5}	1.387×10^{-4}	4.025×10^{-6}	5.145×10^{-5}	5.705×10^{-6}	
	12.675[c]		6.322×10^{-5}	4.340×10^{-5}	1.939×10^{-4}	5.512×10^{-6}	7.357×10^{-5}	8.138×10^{-6}	
	11.386[d]		8.777×10^{-2}	6.120×10^{-2}	1.644×10^{-1}	3.311×10^{-3}	9.813×10^{-2}	1.032×10^{-2}	
^{294}Ts	11.295[a]	2.871×10^{6}	1.280×10^{-2}	2.375×10^{-2}	7.190×10^{-2}	1.531×10^{-3}	3.606×10^{-2}	3.991×10^{-3}	α
	11.405[b]		6.542×10^{-3}	1.225×10^{-2}	3.879×10^{-2}	8.484×10^{-4}	1.866×10^{-2}	2.075×10^{-3}	
	11.246[c]		1.072×10^{-2}	3.199×10^{-2}	9.496×10^{-2}	1.999×10^{-3}	4.853×10^{-2}	5.360×10^{-3}	
	10.744[d]		1.186×10^{-1}	7.579×10^{-1}	1.805	3.399×10^{-2}	1.127	1.217×10^{-1}	
^{290}Mc	10.035[a]	4.786×10^{3}	7.238	1.904×10^{1}	3.821×10^{1}	6.798×10^{-1}	2.640×10^{1}	2.901	α
	10.310[b]		1.074	2.816	6.429	1.202×10^{-1}	3.928	4.382×10^{-1}	
	10.183[c]		2.568	6.743	1.452×10^{1}	2.651×10^{-1}	9.383	1.040	
	9.903[d]		1.859×10^{1}	4.899×10^{1}	9.241×10^{1}	1.608	6.785×10^{1}	7.402	
^{286}Nh	8.965[a]	1.093×10^{1}	3.196×10^{3}	1.229×10^{4}	1.657×10^{4}	2.757×10^{2}	1.583×10^{4}	1.721×10^{3}	SF
	9.516[b]		4.183×10^{1}	1.602×10^{2}	2.889×10^{2}	5.138	2.081×10^{2}	2.343×10^{1}	
	9.527[c]		3.850×10^{1}	1.475×10^{2}	2.667×10^{2}	4.750	1.910×10^{2}	2.152×10^{1}	
	9.351[d]		1.473×10^{2}	5.648×10^{2}	9.331×10^{2}	1.623×10^{1}	7.293×10^{2}	8.128×10^{1}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

TABLE III. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{311}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T^{\alpha}_{1/2}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{311}125$	10.905[a]	2.528×10^{21}	1.257×10^{2}	1.257×10^{2}	7.991×10^{1}	2.554	2.181×10^{1}	2.068×10^{1}	α
	15.873[b]		1.946×10^{-9}	1.013×10^{-9}	3.791×10^{-9}	5.411×10^{-10}	1.060×10^{-9}	2.435×10^{-10}	
	15.957[c]		7.291×10^{-10}	7.291×10^{-10}	2.800×10^{-9}	4.128×10^{-10}	7.832×10^{-10}	1.767×10^{-10}	
	15.811[d]		1.294×10^{-9}	1.294×10^{-9}	4.763×10^{-9}	6.634×10^{-10}	1.331×10^{-9}	3.100×10^{-10}	
$^{307}123$	15.175[a]	2.180×10^{13}	5.161×10^{-9}	5.161×10^{-9}	1.852×10^{-8}	2.197×10^{-9}	4.813×10^{-9}	1.185×10^{-9}	α
	14.261[b]		2.695×10^{-7}	2.695×10^{-7}	7.147×10^{-7}	6.112×10^{-8}	1.855×10^{-7}	5.671×10^{-8}	
	14.395[c]		1.475×10^{-7}	1.475×10^{-7}	4.102×10^{-7}	3.674×10^{-8}	1.065×10^{-7}	3.150×10^{-8}	
	13.169[d]		5.059×10^{-5}	5.059×10^{-5}	9.155×10^{-5}	5.494×10^{-6}	2.372×10^{-5}	9.672×10^{-6}	
$^{303}121$	14.105[a]	2.354×10^{10}	2.344×10^{-7}	1.529×10^{-7}	4.568×10^{-7}	4.011×10^{-8}	1.112×10^{-7}	3.226×10^{-8}	α
	13.346[b]		8.324×10^{-6}	5.473×10^{-6}	1.254×10^{-5}	8.566×10^{-7}	3.058×10^{-6}	1.078×10^{-6}	
	13.403[c]		6.303×10^{-6}	4.142×10^{-6}	9.650×10^{-6}	6.714×10^{-7}	2.353×10^{-6}	8.168×10^{-7}	
	12.348[d]		1.459×10^{-3}	9.717×10^{-4}	1.539×10^{-3}	7.816×10^{-5}	3.760×10^{-4}	1.760×10^{-4}	
$^{299}119$	13.075[a]	5.259×10^{7}	5.399×10^{-6}	5.465×10^{-6}	1.337×10^{-5}	9.104×10^{-7}	3.086×10^{-6}	1.063×10^{-6}	α
	12.796[b]		2.220×10^{-5}	2.239×10^{-5}	4.938×10^{-5}	3.086×10^{-6}	1.141×10^{-5}	4.241×10^{-6}	
	12.816[c]		2.003×10^{-5}	2.021×10^{-5}	4.492×10^{-5}	2.824×10^{-6}	1.038×10^{-5}	3.837×10^{-6}	
	11.536[d]		2.416×10^{-2}	2.389×10^{-2}	3.222×10^{-2}	1.425×10^{-3}	7.500×10^{-3}	4.076×10^{-3}	
^{295}Ts	11.535[a]	2.504×10^{5}	5.251×10^{-3}	5.471×10^{-3}	8.634×10^{-3}	4.131×10^{-4}	1.920×10^{-3}	9.377×10^{-4}	α
	11.326[b]		1.823×10^{-2}	1.899×10^{-2}	2.755×10^{-2}	1.252×10^{-3}	6.139×10^{-3}	3.208×10^{-3}	
	11.206[c]		3.781×10^{-2}	3.940×10^{-2}	5.422×10^{-2}	2.395×10^{-3}	1.210×10^{-2}	6.576×10^{-3}	
	10.644[d]		1.352	1.409	1.515	5.917×10^{-2}	3.402×10^{-1}	2.245×10^{-1}	
^{291}Mc	9.735[a]	9.146×10^{2}	1.025×10^{2}	1.616×10^{2}	1.323×10^{2}	4.746	2.907×10^{1}	2.408×10^{1}	α
	10.219[b]		3.130	5.069	5.226	2.034×10^{-1}	1.138	7.820×10^{-1}	
	10.059[c]		4.007	1.549×10^{1}	1.481×10^{1}	5.601×10^{-1}	3.236	2.361	
	9.693[d]		1.405×10^{2}	2.208×10^{2}	1.774×10^{2}	6.322	3.901×10^{1}	3.286×10^{1}	
^{287}Nh	8.885[a]	1.416	7.917×10^{3}	2.300×10^{4}	1.401×10^{4}	4.891×10^{2}	3.058×10^{3}	3.201×10^{3}	SF
	9.371[b]		1.609×10^{2}	4.668×10^{2}	3.676×10^{2}	1.356×10^{1}	7.921×10^{1}	6.728×10^{1}	
	9.303[c]		2.726×10^{2}	7.908×10^{2}	6.038×10^{2}	2.207×10^{1}	1.303×10^{2}	1.139×10^{2}	
	9.201[d]		6.073×10^{2}	1.763×10^{3}	1.270×10^{3}	4.586×10^{1}	2.749×10^{2}	2.507×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

Here Z_1 and Z_2 are the atomic numbers of the daughter and emitted cluster, r is the distance between fragment centers, and

$$R_i(\alpha_i) = R_{0i}\left[1 + \sum_{\lambda=2,3,4} \beta_{\lambda i} Y_\lambda^{(0)}(\alpha_i)\right], \tag{3}$$

where $R_{0i} = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3}$. Here α_i is the angle between the radius vector and symmetry axis of the ith nuclei (see Fig. 1 of Ref. [49]). The magnitude of the quadrupole-quadrupole interaction term, which is proportional to $\beta_{21}\beta_{22}$, is very small because of its short range character, as compared to the other terms in the expression for deformed Coulomb potential [Eq. (2)]. The deformation values are taken from the recent mass table of Moller *et al.* [51].

The two-term proximity potential for interaction between a deformed and spherical nucleus given by Baltz *et al.* [52] is

$$V_{P2}(r,\theta) = 2\pi\left[\frac{R_1(\alpha)R_C}{R_1(\alpha)+R_C+S}\right]^{1/2}\left[\frac{R_2(\alpha)R_C}{R_2(\alpha)+R_C+S}\right]^{1/2} \times\left\{\left[\varepsilon_0(S) + \frac{R_1(\alpha)+R_C}{2R_1(\alpha)R_C}\varepsilon_1(S)\right] \times\left[\varepsilon_0(S) + \frac{R_2(\alpha)+R_C}{2R_2(\alpha)R_C}\varepsilon_1(S)\right]\right\}^{1/2}, \tag{4}$$

where θ is the angle between the symmetry axis of the deformed nuclei and the line joining the centers of the two interacting nuclei, and α corresponds to the angle between the radius vector and symmetry axis of the nuclei (see Fig. 5 of Ref. [52]). $R_1(\alpha)$ and $R_2(\alpha)$ are the principal radii of curvature of the daughter nuclei, R_C is the radius of the spherical cluster,

TABLE IV. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{312}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T^{\alpha}_{1/2}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{312}125$	9.855[a]	3.027×10^{20}	2.626×10^{5}	2.626×10^{5}	2.381×10^{5}	2.819×10^{3}	4.874×10^{5}	4.129×10^{4}	α
	15.110[b]		2.197×10^{-8}	2.197×10^{-8}	1.472×10^{-7}	6.931×10^{-9}	4.854×10^{-8}	4.907×10^{-9}	
	15.160[c]		1.779×10^{-8}	1.779×10^{-8}	1.214×10^{-7}	5.824×10^{-9}	3.956×10^{-8}	4.004×10^{-9}	
	15.691[d]		4.502×10^{-9}	2.013×10^{-9}	1.626×10^{-8}	9.515×10^{-10}	4.647×10^{-9}	4.764×10^{-10}	
$^{308}123$	15.795[a]	4.149×10^{11}	4.125×10^{-10}	4.125×10^{-10}	4.102×10^{-9}	2.713×10^{-10}	9.233×10^{-10}	1.005×10^{-10}	α
	14.806[b]		2.356×10^{-8}	2.356×10^{-8}	1.709×10^{-7}	7.785×10^{-9}	4.914×10^{-8}	5.219×10^{-9}	
	14.955[c]		1.249×10^{-8}	1.249×10^{-8}	9.524×10^{-8}	4.580×10^{-9}	2.636×10^{-8}	2.810×10^{-9}	
	14.059[d]		6.548×10^{-7}	6.548×10^{-7}	3.692×10^{-6}	1.295×10^{-7}	1.299×10^{-6}	1.352×10^{-7}	
$^{304}121$	14.095[a]	2.168×10^{9}	2.459×10^{-7}	1.544×10^{-7}	1.047×10^{-6}	4.026×10^{-8}	2.949×10^{-7}	3.252×10^{-8}	α
	13.313[b]		1.547×10^{-5}	6.209×10^{-6}	3.192×10^{-5}	9.479×10^{-7}	1.128×10^{-5}	1.214×10^{-6}	
	13.385[c]		7.018×10^{-6}	4.362×10^{-6}	2.301×10^{-5}	6.992×10^{-7}	7.958×10^{-6}	8.586×10^{-7}	
	12.298[d]		1.953×10^{-3}	1.234×10^{-3}	4.371×10^{-3}	9.608×10^{-5}	2.142×10^{-3}	2.227×10^{-4}	
$^{300}119$	13.025[a]	6.300×10^{6}	6.974×10^{-6}	6.768×10^{-6}	3.704×10^{-5}	1.090×10^{-6}	1.160×10^{-5}	1.309×10^{-6}	α
	12.604[b]		1.323×10^{-4}	5.852×10^{-5}	2.734×10^{-4}	7.083×10^{-6}	9.790×10^{-5}	1.089×10^{-5}	
	12.614[c]		5.756×10^{-5}	5.553×10^{-5}	2.611×10^{-4}	6.785×10^{-6}	9.324×10^{-5}	1.037×10^{-5}	
	11.456[d]		3.931×10^{-2}	3.722×10^{-2}	1.107×10^{-1}	2.108×10^{-3}	5.938×10^{-2}	6.314×10^{-3}	
^{296}Ts	11.635[a]	3.671×10^{4}	2.836×10^{-3}	2.944×10^{-3}	1.103×10^{-2}	2.374×10^{-4}	4.490×10^{-3}	5.086×10^{-4}	α
	11.533[b]		5.146×10^{-3}	5.340×10^{-3}	1.925×10^{-2}	4.037×10^{-4}	8.139×10^{-3}	9.179×10^{-4}	
	11.484[c]		6.870×10^{-3}	7.129×10^{-3}	2.507×10^{-2}	5.195×10^{-4}	1.079×10^{-2}	1.215×10^{-3}	
	10.744[d]		6.797×10^{-1}	7.047×10^{-1}	1.805	3.156×10^{-2}	1.040	1.132×10^{-1}	
^{292}Mc	9.595[a]	2.143×10^{2}	3.728×10^{2}	4.448×10^{2}	7.743×10^{2}	1.192×10^{1}	6.070×10^{2}	6.563×10^{1}	SF
	9.960[b]		2.486×10^{1}	3.023×10^{1}	6.298×10^{1}	1.026	4.153×10^{1}	4.584	
	9.799[c]		8.059×10^{1}	9.719×10^{1}	1.874×10^{2}	2.974	1.332×10^{2}	1.458×10^{1}	
	9.513[d]		6.995×10^{2}	8.310×10^{2}	1.390×10^{3}	2.116×10^{1}	1.135×10^{3}	1.221×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

S is the distance between the surfaces along the straight line connecting the fragments, and $\varepsilon_0(S)$ and $\varepsilon_1(S)$ are the one dimensional slab-on-slab functions.

For the prescission (overlap) region, simple power law interpolation [53] has been used. The potential for the internal part of the barrier is given as

$$V = a_0(L - L_0)^n, \quad \text{for } z < 0, \tag{5}$$

where $L = z + 2C_1 + 2C_2$ fm and $L_0 = 2C$, where C, C_1 and C_2 are the Süsmann central radii of parent nuclei, daughter nuclei, and emitted cluster respectively. The constants a_0 and n are determined by the smooth matching of the two potentials at the touching point.

The barrier penetrability P using the one dimensional Wentzel-Kramers-Brillouin approximation is

$$P = \exp\left\{-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}dz\right\}. \tag{6}$$

Here the mass parameter is replaced by $\mu = mA_1A_2/A$, where m is the nucleon mass and A_1, A_2 are the mass numbers of daughter and emitted cluster respectively. V represents the interacting potential between two nuclei. The turning points a and b are determined from the equation $V(a) = V(b) = Q$, where Q is the energy released.

The half-life of nuclei which decay through α emission can be calculated by means of WKB approximation. The α-decay half-lives can be obtained using

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\nu P}\right), \tag{7}$$

where λ is the decay constant, ν is the assault frequency, and P is the barrier penetrability. The assault frequency ν can be calculated as

$$\nu = \left(\frac{\omega}{2\pi}\right) = \left(\frac{2E_v}{h}\right). \tag{8}$$

TABLE V. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{313}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T_{1/2}^{\alpha}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{313}125$	9.235[a]	1.290×10^{19}	4.781×10^{7}	4.279×10^{7}	1.350×10^{7}	3.173×10^{5}	3.353×10^{6}	6.587×10^{6}	α
	14.319[b]		7.041×10^{-7}	6.849×10^{-7}	1.670×10^{-6}	1.263×10^{-7}	4.276×10^{-7}	1.425×10^{-7}	
	14.312[c]		7.270×10^{-7}	7.071×10^{-7}	1.717×10^{-6}	1.296×10^{-7}	4.397×10^{-7}	1.468×10^{-7}	
	15.671[d]		2.130×10^{-9}	2.104×10^{-9}	7.964×10^{-9}	9.832×10^{-10}	2.050×10^{-9}	4.968×10^{-10}	
$^{309}123$	15.815[a]	6.764×10^{9}	3.684×10^{-10}	3.684×10^{-10}	1.737×10^{-9}	2.461×10^{-10}	4.161×10^{-10}	8.984×10^{-11}	α
	15.274[b]		3.197×10^{-9}	3.197×10^{-9}	1.272×10^{-8}	1.464×10^{-9}	3.046×10^{-9}	7.402×10^{-10}	
	15.447[c]		1.583×10^{-9}	1.583×10^{-9}	6.655×10^{-9}	8.177×10^{-10}	1.594×10^{-9}	3.726×10^{-10}	
	14.879[d]		1.664×10^{-8}	1.664×10^{-8}	5.825×10^{-8}	5.790×10^{-9}	1.394×10^{-8}	3.707×10^{-9}	
$^{305}121$	14.105[a]	4.949×10^{7}	1.424×10^{-7}	1.424×10^{-7}	4.568×10^{-7}	3.743×10^{-8}	1.025×10^{-7}	3.000×10^{-8}	α
	13.304[b]		6.263×10^{-6}	6.263×10^{-6}	1.513×10^{-5}	9.508×10^{-7}	3.399×10^{-6}	1.223×10^{-6}	
	13.371[c]		4.507×10^{-6}	4.507×10^{-6}	1.118×10^{-5}	7.178×10^{-7}	2.512×10^{-6}	8.882×10^{-7}	
	12.238[d]		1.660×10^{-3}	1.660×10^{-3}	2.710×10^{-3}	1.243×10^{-4}	6.100×10^{-4}	2.982×10^{-4}	
$^{301}119$	13.075[a]	1.936×10^{5}	7.729×10^{-6}	5.090×10^{-6}	1.337×10^{-5}	8.483×10^{-7}	2.841×10^{-6}	9.880×10^{-7}	α
	12.459[b]		1.834×10^{-4}	1.216×10^{-4}	2.544×10^{-4}	1.340×10^{-5}	5.423×10^{-5}	2.241×10^{-5}	
	12.462[c]		1.804×10^{-4}	1.197×10^{-4}	2.503×10^{-4}	1.319×10^{-5}	5.335×10^{-5}	2.203×10^{-5}	
	11.406[d]		7.219×10^{-2}	4.859×10^{-2}	6.679×10^{-2}	2.661×10^{-3}	1.433×10^{-2}	8.211×10^{-3}	
^{297}Ts	11.765[a]	1.616×10^{3}	1.399×10^{-3}	1.345×10^{-3}	2.503×10^{-3}	1.182×10^{-4}	5.112×10^{-4}	2.347×10^{-4}	α
	11.649[b]		2.729×10^{-3}	2.620×10^{-3}	4.665×10^{-3}	2.136×10^{-4}	9.538×10^{-4}	4.540×10^{-4}	
	11.630[c]		3.048×10^{-3}	2.925×10^{-3}	5.168×10^{-3}	2.355×10^{-4}	1.057×10^{-3}	5.061×10^{-4}	
	10.864[d]		3.300×10^{-1}	3.130×10^{-1}	3.985×10^{-1}	1.514×10^{-2}	8.218×10^{-2}	5.070×10^{-2}	
^{293}Mc	9.435[a]	1.593×10^{1}	9.380×10^{2}	1.464×10^{3}	1.108×10^{3}	3.532×10^{1}	2.254×10^{2}	2.135×10^{2}	SF
	9.742[b]		9.040×10^{1}	1.428×10^{2}	1.264×10^{2}	4.209	2.557×10^{1}	2.135×10^{1}	
	9.619[c]		2.278×10^{2}	3.580×10^{2}	2.970×10^{2}	9.711	6.021×10^{1}	5.283×10^{1}	
	9.363[d]		1.085×10^{3}	2.568×10^{3}	1.877×10^{3}	5.928×10^{1}	3.824×10^{2}	3.733×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

Here E_v is the empirical vibration energy, which is given by [54]

$$E_v = Q\left\{0.056 + 0.039\exp\left[\frac{(4-A_2)}{2.5}\right]\right\}, \quad \text{for } A_2 \geqslant 4. \quad (9)$$

The α particle vibrates in a harmonic oscillator potential with a frequency ω, which depends on the vibrational energy E_v. We can identify this frequency as the assault frequency v and the expression for the empirical vibration energy E_v is used only for finding the assault frequency v.

In the case of spherical nuclei (in CPPM), the interacting barrier is given by

$$V = \frac{Z_1 Z_2 e^2}{r} + V_P(z) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2}, \quad \text{for } z > 0, \quad (10)$$

where z is the distance between the near surfaces of the fragments. $V_P(z)$ is the proximity potential given by Blocki *et al.* [55,56] as

$$V_p(z) = 4\pi\gamma b\left[\frac{C_1 C_2}{(C_1+C_2)}\right]\Phi\left(\frac{z}{b}\right), \quad (11)$$

with the nuclear surface tension coefficient

$$\gamma = 0.9517[1 - 1.7826(N-Z)^2/A^2]\,\text{MeV/fm}^2. \quad (12)$$

Here N, Z, and A represent the neutron, proton, and mass number of the parent nuclei. Φ represents the universal proximity potential [56] given as

$$\Phi(\varepsilon) = -4.41 e^{-\varepsilon/0.7176}, \quad \text{for } \varepsilon > 1.9475, \quad (13)$$

$$\Phi(\varepsilon) = -1.7817 + 0.9270\varepsilon + 0.0169\varepsilon^2 - 0.05148\varepsilon^3, \quad \text{for } 0 \leqslant \varepsilon \leqslant 1.9475, \quad (14)$$

TABLE VI. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{314}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T^{\alpha}_{1/2}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{314}125$	9.795[a]	9.783×10^{17}	4.803×10^{5}	3.917×10^{5}	3.723×10^{5}	4.057×10^{3}	7.245×10^{5}	6.171×10^{4}	α
	14.023[b]		2.926×10^{-6}	2.607×10^{-6}	1.310×10^{-5}	3.942×10^{-7}	5.343×10^{-6}	5.289×10^{-7}	
	13.987[c]		3.591×10^{-6}	3.089×10^{-6}	1.532×10^{-5}	4.555×10^{-7}	6.310×10^{-6}	6.241×10^{-7}	
	15.281[d]		1.145×10^{-8}	9.986×10^{-9}	7.607×10^{-8}	3.566×10^{-9}	2.220×10^{-8}	2.270×10^{-9}	
$^{310}123$	14.065[a]	2.205×10^{9}	5.973×10^{-7}	5.931×10^{-7}	3.599×10^{-6}	1.181×10^{-7}	1.167×10^{-6}	1.224×10^{-7}	α
	14.540[b]		7.008×10^{-8}	6.969×10^{-8}	4.967×10^{-7}	1.921×10^{-8}	1.415×10^{-7}	1.503×10^{-8}	
	14.678[c]		3.832×10^{-8}	3.813×10^{-8}	2.842×10^{-7}	1.155×10^{-8}	7.804×10^{-8}	8.320×10^{-9}	
	14.679[d]		3.815×10^{-8}	3.796×10^{-8}	2.832×10^{-7}	1.151×10^{-8}	7.774×10^{-8}	8.289×10^{-9}	
$^{306}121$	14.775[a]	6.017×10^{5}	7.319×10^{-9}	7.319×10^{-9}	6.695×10^{-8}	3.064×10^{-9}	1.450×10^{-8}	1.642×10^{-9}	α
	13.846[b]		4.515×10^{-7}	4.515×10^{-7}	3.020×10^{-6}	9.954×10^{-8}	8.426×10^{-7}	9.291×10^{-8}	
	13.931[c]		3.046×10^{-7}	3.046×10^{-7}	2.096×10^{-6}	7.110×10^{-8}	5.707×10^{-7}	6.309×10^{-8}	
	13.048[d]		2.173×10^{-5}	2.173×10^{-5}	1.094×10^{-4}	2.787×10^{-6}	3.875×10^{-5}	4.166×10^{-6}	
$^{302}119$	13.045[a]	1.248×10^{4}	5.709×10^{-6}	5.709×10^{-6}	3.376×10^{-5}	9.318×10^{-7}	9.696×10^{-6}	1.104×10^{-6}	α
	12.459[b]		1.174×10^{-4}	1.174×10^{-4}	5.572×10^{-4}	1.289×10^{-5}	1.932×10^{-4}	2.154×10^{-5}	
	12.483[c]		1.033×10^{-4}	1.033×10^{-4}	4.965×10^{-4}	1.156×10^{-5}	1.709×10^{-4}	1.906×10^{-5}	
	11.366[d]		5.981×10^{-2}	5.981×10^{-2}	1.842×10^{-1}	3.189×10^{-3}	9.433×10^{-2}	1.007×10^{-2}	
^{298}Ts	11.855[a]	1.285×10^{2}	7.791×10^{-4}	7.791×10^{-4}	3.423×10^{-3}	7.262×10^{-5}	1.188×10^{-3}	1.369×10^{-4}	α
	11.549[b]		4.531×10^{-3}	4.531×10^{-3}	1.759×10^{-2}	3.445×10^{-4}	6.821×10^{-3}	7.761×10^{-4}	
	11.521[c]		5.341×10^{-3}	5.341×10^{-3}	2.053×10^{-2}	3.992×10^{-4}	8.046×10^{-3}	9.143×10^{-4}	
	10.794[d]		4.743×10^{-1}	4.743×10^{-1}	1.334	2.188×10^{-2}	6.944×10^{-1}	7.638×10^{-2}	
^{294}Mc	9.445[a]	1.998	1.111×10^{3}	1.307×10^{3}	2.265×10^{3}	3.168×10^{1}	1.764×10^{3}	1.907×10^{2}	SF
	9.726[b]		1.698×10^{2}	1.552×10^{2}	3.104×10^{2}	4.518	2.108×10^{2}	2.316×10^{1}	
	9.680[c]		1.174×10^{2}	2.186×10^{2}	4.250×10^{2}	6.144	2.950×10^{2}	3.233×10^{1}	
	9.413[d]		1.426×10^{3}	1.676×10^{3}	2.862×10^{3}	3.986×10^{1}	2.265×10^{3}	2.444×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

with $\varepsilon = z/b$, where $b \approx 1$ fm is the width (diffuseness) of the nuclear surface. The Süsmann central radii C_i of the fragments are related to the sharp radii R_i as

$$C_i = R_i - \left(\frac{b^2}{R_i}\right) \text{fm}. \quad (15)$$

For R_i, we use semiempirical formula in terms of mass number A_i as [55]

$$R_i = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3} \text{ fm}. \quad (16)$$

In CPPM, with the potential in Eq. (10), the penetrability and half-lives can be calculated using Eqs. (6) and (7).

III. RESULTS AND DISCUSSION

SHN usually exhibit a sequential α decay chain followed by subsequent SF. Most of the SHN are identified from their α decay chains. The α decay chains provide clear signatures of the nucleus in the beginning of the decay chain. The experimentally measured quantities in the α decay are the α decay energy (Q value) and the half-lives for the decay. So the theoretical predictions on these two quantities are very important for designing the experiments which can be used to explore the limits of the predicted island of stability.

The decay properties of the isotopes of SHN with $Z = 125$, within the range $303 \leqslant A \leqslant 339$, are studied in the present work. The one-proton and two-proton separation energies are calculated to find the nuclei which decay through proton emission. Four different mass tables are used for calculating the Q value for the decay and six different formalisms are used for calculating the α-decay half-lives.

A. Proton separation energy

The one-proton and two-proton separation energies of all isotopes under study are calculated to identify the proton

TABLE VII. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{315}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T_{1/2}^{\alpha}$ (s)						Mode of decay
			CPPMDN	CPPM	VSS	UNIV	Royer	UDL	
$^{315}125$	9.815[a]	2.504×10^{16}	5.692×10^{5}	3.219×10^{5}	1.459×10^{5}	3.374×10^{3}	3.356×10^{4}	5.085×10^{4}	α
	13.811[b]		1.229×10^{-5}	6.900×10^{-6}	1.519×10^{-5}	9.049×10^{-7}	3.577×10^{-6}	1.373×10^{-6}	
	13.716[c]		1.946×10^{-5}	1.092×10^{-5}	2.327×10^{-5}	1.345×10^{-6}	5.478×10^{-6}	2.158×10^{-6}	
	14.841[d]		1.113×10^{-7}	6.248×10^{-8}	1.946×10^{-7}	1.650×10^{-8}	4.603×10^{-8}	1.362×10^{-8}	
$^{311}123$	13.355[a]	8.109×10^{7}	1.798×10^{-5}	1.720×10^{-5}	3.842×10^{-5}	2.121×10^{-6}	8.455×10^{-6}	3.338×10^{-6}	α
	13.699[b]		3.330×10^{-6}	3.205×10^{-6}	8.087×10^{-6}	4.985×10^{-7}	1.781×10^{-6}	6.408×10^{-7}	
	13.801[c]		2.043×10^{-6}	1.970×10^{-6}	5.148×10^{-6}	3.282×10^{-7}	1.134×10^{-6}	3.972×10^{-7}	
	14.539[d]		6.929×10^{-8}	6.760×10^{-8}	2.268×10^{-7}	1.863×10^{-8}	5.000×10^{-8}	1.455×10^{-8}	
$^{307}121$	14.805[a]	6.820×10^{3}	6.229×10^{-9}	6.229×10^{-9}	2.710×10^{-8}	2.664×10^{-9}	5.595×10^{-9}	1.399×10^{-9}	α
	14.372[b]		4.031×10^{-8}	4.031×10^{-8}	1.516×10^{-7}	1.274×10^{-8}	3.133×10^{-8}	8.674×10^{-9}	
	14.499[c]		2.312×10^{-8}	2.312×10^{-8}	9.093×10^{-8}	7.995×10^{-9}	1.878×10^{-8}	5.046×10^{-9}	
	13.778[d]		5.990×10^{-7}	5.990×10^{-7}	1.843×10^{-6}	1.261×10^{-7}	3.812×10^{-7}	1.223×10^{-7}	
$^{303}119$	13.105[a]	1.959×10^{2}	4.092×10^{-6}	4.092×10^{-6}	1.165×10^{-5}	6.954×10^{-7}	2.280×10^{-6}	7.941×10^{-7}	α
	12.450[b]		1.190×10^{-4}	1.190×10^{-4}	2.655×10^{-4}	1.299×10^{-5}	5.214×10^{-5}	2.182×10^{-5}	
	12.455[c]		1.159×10^{-4}	1.159×10^{-4}	2.583×10^{-4}	1.266×10^{-5}	5.073×10^{-5}	2.119×10^{-5}	
	11.276[d]		1.003×10^{-1}	1.003×10^{-1}	1.402×10^{-1}	5.036×10^{-3}	2.773×10^{-2}	1.677×10^{-2}	
^{299}Ts	11.855[a]	2.912	7.528×10^{-4}	7.528×10^{-4}	1.557×10^{-3}	7.006×10^{-5}	2.927×10^{-4}	1.320×10^{-4}	α
	11.489[b]		6.231×10^{-3}	6.231×10^{-3}	1.110×10^{-2}	4.537×10^{-4}	2.093×10^{-3}	1.059×10^{-3}	
	11.476[c]		4.196×10^{-3}	6.729×10^{-3}	1.194×10^{-2}	4.865×10^{-4}	2.252×10^{-3}	1.144×10^{-3}	
	10.734[d]		6.765×10^{-1}	6.765×10^{-1}	8.729×10^{-1}	2.996×10^{-2}	1.660×10^{-1}	1.083×10^{-1}	
^{295}Mc	9.575[a]	5.779×10^{-2}	4.656×10^{2}	4.656×10^{2}	4.059×10^{2}	1.223×10^{1}	7.584×10^{1}	6.849×10^{1}	SF
	9.753[b]		1.227×10^{2}	1.227×10^{2}	1.168×10^{2}	3.613	2.174×10^{1}	1.827×10^{1}	
	9.726[c]		8.783×10^{1}	1.499×10^{2}	1.413×10^{2}	4.354	2.633×10^{1}	2.236×10^{1}	
	9.523[d]		6.922×10^{2}	6.922×10^{2}	5.889×10^{2}	1.762×10^{1}	1.101×10^{2}	1.016×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

emitters using the following relations:

$$S(p) = -\Delta M(A,Z) + \Delta M(A-1,Z-1) + \Delta M_H = -Q(\gamma,p), \quad (17)$$

$$S(2p) = -\Delta M(A,Z) + \Delta M(A-2,Z-2) + 2\Delta M_H = -Q(\gamma,2p), \quad (18)$$

where the terms $S(p)$ and $S(2p)$ are the one-proton separation energy and the two-proton separation energy of the nuclei, $\Delta M(A,Z)$, ΔM_H, $\Delta M(A-1,Z-1)$, and $\Delta M(A-2,Z-2)$ represent the mass excess of the parent nuclei, the mass excess of the proton, the mass excess of the daughter nuclei produced during the one-proton radioactivity, and the mass excess of the daughter nuclei produced during the two-proton radioactivity respectively. $Q(\gamma, p)$ and $Q(\gamma, 2p)$ represent respectively the Q values for the one-proton radioactivity and two-proton radioactivity. Here γ stands for the gamma radiation accompanied with the proton emission. The mass excess for calculating the one-proton and two-proton separation energies is taken from the mass table of Moller *et al.* [51]. The isotopes of $Z = 125$ which may decay through proton emission are given in Table I. It is seen that the isotopes $303 \leqslant A \leqslant 309$ may lie beyond the proton drip line with negative proton separation energy.

B. α-decay energy (Q_α)

The most important quantity determining the α-decay half-life is the Q value of the decay. The Q value for the decay can be calculated using the equation

$$Q = \Delta M_p - (\Delta M_\alpha + \Delta M_d) + k\left(Z_p^{\varepsilon} - Z_d^{\varepsilon}\right). \quad (19)$$

The mass excess of the parent, daughter, and the α particle are represented by $\Delta M_p, \Delta M_d$, and ΔM_α. The electron

TABLE VIII. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{316}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T^{\alpha}_{1/2}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{316}125$	9.785[a]	7.771×10^{14}	5.013×10^{5}	3.938×10^{5}	4.012×10^{5}	4.052×10^{3}	7.249×10^{5}	6.223×10^{4}	α
	13.761[b]		1.001×10^{-5}	8.478×10^{-6}	4.178×10^{-5}	1.076×10^{-6}	1.697×10^{-5}	1.680×10^{-6}	
	13.652[c]		1.704×10^{-5}	1.441×10^{-5}	6.860×10^{-5}	1.706×10^{-6}	2.878×10^{-5}	2.840×10^{-6}	
	14.381[d]		5.429×10^{-7}	4.644×10^{-7}	2.829×10^{-6}	8.970×10^{-8}	9.648×10^{-7}	9.713×10^{-8}	
$^{312}123$	13.335[a]	3.178×10^{6}	2.080×10^{-5}	1.835×10^{-5}	9.262×10^{-5}	2.233×10^{-6}	3.435×10^{-5}	3.551×10^{-6}	α
	12.932[b]		1.623×10^{-4}	1.432×10^{-4}	6.246×10^{-4}	1.331×10^{-5}	2.626×10^{-4}	2.681×10^{-5}	
	12.942[c]		1.541×10^{-4}	1.359×10^{-4}	5.965×10^{-4}	1.274×10^{-5}	2.500×10^{-4}	2.553×10^{-5}	
	14.229[d]		2.957×10^{-7}	2.611×10^{-7}	1.796×10^{-6}	5.818×10^{-8}	5.141×10^{-7}	5.454×10^{-8}	
$^{308}121$	13.735[a]	3.453×10^{2}	7.131×10^{-7}	7.082×10^{-7}	4.872×10^{-6}	1.444×10^{-7}	1.296×10^{-6}	1.435×10^{-7}	α
	14.103[b]		1.303×10^{-7}	1.296×10^{-7}	1.012×10^{-6}	3.401×10^{-8}	2.425×10^{-7}	2.715×10^{-8}	
	14.263[c]		6.347×10^{-8}	6.315×10^{-8}	5.216×10^{-7}	1.854×10^{-8}	1.196×10^{-7}	1.345×10^{-8}	
	13.568[d]		1.576×10^{-6}	1.565×10^{-6}	1.017×10^{-5}	2.852×10^{-7}	2.842×10^{-6}	3.131×10^{-7}	
$^{304}119$	13.855[a]	1.482	1.112×10^{-7}	1.112×10^{-7}	9.416×10^{-7}	3.166×10^{-8}	1.963×10^{-7}	2.311×10^{-8}	α
	12.963[b]		8.041×10^{-6}	8.041×10^{-6}	4.940×10^{-5}	1.239×10^{-6}	1.344×10^{-5}	1.537×10^{-6}	
	12.982[c]		7.308×10^{-6}	7.308×10^{-6}	4.534×10^{-5}	1.143×10^{-6}	1.226×10^{-5}	1.403×10^{-6}	
	12.086[d]		8.382×10^{-4}	8.382×10^{-4}	3.695×10^{-3}	7.162×10^{-5}	1.344×10^{-3}	1.489×10^{-4}	
^{300}Ts	11.875[a]	1.333×10^{-1}	6.500×10^{-4}	6.500×10^{-4}	3.083×10^{-3}	6.120×10^{-5}	9.804×10^{-4}	1.140×10^{-4}	α
	11.580[b]		3.528×10^{-3}	3.528×10^{-3}	1.485×10^{-2}	2.727×10^{-4}	5.256×10^{-3}	6.036×10^{-4}	
	11.581[c]		3.508×10^{-3}	3.508×10^{-3}	1.482×10^{-2}	2.721×10^{-4}	5.244×10^{-3}	6.022×10^{-4}	
	10.694[d]		8.491×10^{-1}	8.491×10^{-1}	2.449	3.656×10^{-2}	1.227	1.354×10^{-1}	
^{296}Mc	9.585[a]	3.498×10^{-3}	2.782×10^{2}	4.169×10^{2}	8.311×10^{2}	1.099×10^{1}	5.575×10^{2}	6.130×10^{1}	SF
	9.637[b]		1.876×10^{2}	2.815×10^{2}	5.780×10^{2}	7.702	3.782×10^{2}	4.170×10^{1}	
	9.646[c]		1.753×10^{2}	2.631×10^{2}	5.392×10^{2}	7.195	3.511×10^{2}	3.874×10^{1}	
	9.463[d]		7.102×10^{2}	1.061×10^{3}	1.992×10^{3}	2.590×10^{1}	1.419×10^{3}	1.549×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

screening effect on the energy of α particle is included by adding the term $k(Z_p^\varepsilon - Z_d^\varepsilon)$ in Eq. (19). The term kZ^ε is the total binding energy of Z electrons in the atom. Here $k = 8.7$ eV and $\varepsilon = 2.517$ for nuclei with $Z \geqslant 60$ and $k = 13.6$ eV and $\varepsilon = 2.408$ for nuclei with $Z < 60$ [57,58]. The Q value must be positive for α decay to occur.

The sensitivity of the decay energy to the mass models used has been a subject of study in many theoretical papers [40,59–62]. It was seen that a change in Q value by 1 MeV will make several order changes in the half-life calculation. So one must take into account such changes while calculating the α-decay half-lives.

In the present paper four different mass models, the mass table of Moller *et al.* [51], the WS4 mass table [63], the WS3 mass table [64], and the mass table of Koura *et al.* [65], are used for calculating the Q values for the isotopes in the decay chains of nuclei with $Z = 125$. The mass table of Moller *et al.* [51] is based on the finite range droplet macroscopic and folded-Yukawa single-particle microscopic nuclear-structure models. The WS3 mass model [64] considers the total energy of the nucleus as the sum of the liquid drop energy, Strutisnsky shell correction, and the residual correction. By taking into account the surface diffuseness correction for unstable nuclei, the accuracy of this macroscopic-microscopic formula is further improved (WS4) [63]. The inclusion of the radial basis function (RBF) made the accuracy and predictive power of the WS4 mass model much better. The mass table of Koura *et al.* [65] presents the ground state mass on a spherical basis with an improved even-odd term.

The difference in Q value using different mass models is evident from Tables II–XI. For example, in the case of ^{294}Ts, the Q value calculated using the mass table of Moller *et al.* [51] is 11.295 MeV whereas the WS4 mass table [63], WS3 mass table [64], and the mass table of Koura *et al.* [65] gives the Q value as 12.745, 12. 675, and 11. 386 MeV respectively. The corresponding changes in the half-lives are also given in the table. It is seen that the Q values calculated using WS4 [63] and WS3 [64] mass tables will not show much difference. It is

TABLE IX. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{317}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T_{1/2}^{\alpha}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{317}125$	9.795[a]	9.096×10^{12}	4.094×10^{5}	3.506×10^{5}	1.694×10^{5}	3.626×10^{3}	3.593×10^{4}	5.550×10^{4}	α
	13.717[b]		1.071×10^{-5}	1.013×10^{-5}	2.322×10^{-5}	1.252×10^{-6}	5.041×10^{-6}	2.004×10^{-6}	
	13.625[c]		1.681×10^{-5}	1.588×10^{-5}	3.515×10^{-5}	1.840×10^{-6}	7.628×10^{-6}	3.108×10^{-6}	
	13.651[d]		1.479×10^{-5}	1.398×10^{-5}	3.133×10^{-5}	1.653×10^{-6}	6.799×10^{-6}	2.751×10^{-6}	
$^{313}123$	13.405[a]	5.175×10^{4}	1.405×10^{-5}	1.252×10^{-5}	3.051×10^{-5}	1.596×10^{-6}	6.192×10^{-6}	2.434×10^{-6}	α
	12.691[b]		5.528×10^{-4}	4.940×10^{-4}	9.334×10^{-4}	3.930×10^{-5}	1.892×10^{-4}	9.114×10^{-5}	
	12.651[c]		6.852×10^{-4}	6.124×10^{-4}	1.139×10^{-3}	4.743×10^{-5}	2.310×10^{-4}	1.126×10^{-4}	
	14.049[d]		6.469×10^{-7}	5.755×10^{-7}	1.753×10^{-6}	1.134×10^{-7}	3.561×10^{-7}	1.181×10^{-7}	
$^{309}121$	13.055[a]	8.341	1.909×10^{-5}	1.891×10^{-5}	4.804×10^{-5}	2.427×10^{-6}	9.171×10^{-6}	3.603×10^{-6}	α
	13.295[b]		5.748×10^{-6}	5.700×10^{-6}	1.582×10^{-5}	8.616×10^{-7}	3.018×10^{-6}	1.110×10^{-6}	
	13.410[c]		3.270×10^{-6}	3.244×10^{-6}	9.358×10^{-6}	5.291×10^{-7}	1.785×10^{-6}	6.367×10^{-7}	
	13.338[d]		4.651×10^{-6}	4.613×10^{-6}	1.301×10^{-5}	7.186×10^{-7}	2.482×10^{-6}	9.027×10^{-7}	
$^{305}119$	13.855[a]	1.161×10^{-2}	1.076×10^{-7}	1.076×10^{-7}	4.284×10^{-7}	3.060×10^{-8}	7.698×10^{-8}	2.229×10^{-8}	α
	13.459[b]		6.838×10^{-7}	6.838×10^{-7}	2.367×10^{-6}	1.478×10^{-7}	4.261×10^{-7}	1.365×10^{-7}	
	13.535[c]		4.766×10^{-7}	4.766×10^{-7}	1.699×10^{-6}	1.088×10^{-7}	3.058×10^{-7}	9.605×10^{-8}	
	12.876[d]		1.208×10^{-5}	1.208×10^{-5}	3.384×10^{-5}	1.753×10^{-6}	6.110×10^{-6}	2.288×10^{-6}	
^{301}Ts	11.935[a]	1.373×10^{-3}	4.489×10^{-4}	4.489×10^{-4}	1.026×10^{-3}	4.391×10^{-5}	1.775×10^{-4}	7.893×10^{-5}	α
	11.643[b]		2.364×10^{-3}	2.364×10^{-3}	4.808×10^{-3}	1.903×10^{-4}	8.343×10^{-4}	4.060×10^{-4}	
	11.624[c]		2.640×10^{-3}	2.640×10^{-3}	5.338×10^{-3}	2.102×10^{-4}	9.266×10^{-4}	4.536×10^{-4}	
	10.604[d]		1.486	1.486	1.940	6.021×10^{-2}	3.405×10^{-1}	2.352×10^{-1}	
^{297}Mc	9.585[a]	5.032×10^{-5}	2.690×10^{2}	4.029×10^{2}	3.782×10^{2}	1.059×10^{1}	6.507×10^{1}	5.916×10^{1}	SF
	9.622[b]		2.032×10^{2}	3.046×10^{2}	2.914×10^{2}	8.205	5.012×10^{1}	4.488×10^{1}	
	9.608[c]		2.259×10^{2}	3.386×10^{2}	3.210×10^{2}	9.018	5.521×10^{1}	4.972×10^{1}	
	9.403[d]		1.096×10^{3}	1.633×10^{3}	1.401×10^{3}	3.825×10^{1}	2.419×10^{2}	2.373×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

also evident that the discrepancies in the Q value increases in the very heavy region. For example, for isotope $^{310}125$, the Q value with the mass table of Moller *et al.* [51] is 11.345 MeV. The Q value for the same isotope with WS4 [63] and WS3 [64] mass tables are 15.938 and 16.066 MeV. The mass table of Koura *et al.* [65] gives the Q value of $^{310}125$ as 14.951 MeV. The half-lives also vary significantly in the very heavy region. Different studies [61,62] reveal that among various theoretical models, the WS4 mass model is the most accurate one to predict the Q values in the superheavy region.

C. α-decay half-lives ($T_{1/2}^{\alpha}$)

Various phenomenological formulas are used to calculate the α-decay half-lives. In the present work, CPPMDN [47], CPPM [66], the Viola-Seaborg Sobiczewski (VSS) semiempirical relation [67,68], the universal curve (UNIV) of Poenaru *et al.* [69,70], the analytical formula of Royer [71], and the universal decay law (UDL) of Qi *et al.* [72,73] are used for calculating the α half-lives. For a single isotope, the half-lives are calculated corresponding to four different Q values using these six models.

One of the famous and most frequently used expressions for calculating the α-decay half-lives is given by Viola and Seaborg as

$$\log_{10}(T_{1/2}) = (aZ + b)Q^{-1/2} + cZ + d + h_{\log}. \quad (20)$$

Here Z is the atomic number of the parent nucleus and a, b, c, d are adjustable parameters. The hindrance factor for nuclei with unpaired nucleons is given by the quantity $h_{\log}$. Instead of using the original set of constants given by Viola and Seaborg [67], the values determined by Sobiczewski *et al.* [68] have been used here. The constants are $a = 1.66175$, $b = -8.5166$, $c = -0.20228$, $d = -33.9069$, and

$$h_{\log} = \begin{cases} 0 & \text{for} \quad Z = \text{even} \quad N = \text{even} \\ 0.772 & \text{for} \quad Z = \text{odd} \quad N = \text{even} \\ 1.066 & \text{for} \quad Z = \text{even} \quad N = \text{odd} \\ 1.114 & \text{for} \quad Z = \text{odd} \quad N = \text{odd} \end{cases}. \quad (21)$$

TABLE X. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotope $^{318}125$ and its decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T^{\alpha}_{1/2}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{318}125$	9.885[a]	1.384×10^{11}	2.004×10^{5}	1.660×10^{5}	1.907×10^{5}	1.811×10^{3}	3.036×10^{5}	2.640×10^{4}	α
	13.374[b]		6.014×10^{-5}	5.342×10^{-5}	2.466×10^{-4}	5.241×10^{-6}	1.039×10^{-4}	1.025×10^{-5}	
	13.475[c]		3.559×10^{-5}	3.220×10^{-5}	1.541×10^{-4}	3.379×10^{-6}	6.295×10^{-5}	6.228×10^{-6}	
	13.641[d]		1.562×10^{-5}	1.418×10^{-5}	7.206×10^{-5}	1.666×10^{-6}	2.803×10^{-5}	2.786×10^{-6}	
$^{314}123$	13.315[a]	1.232×10^{3}	2.131×10^{-5}	1.893×10^{-5}	1.016×10^{-4}	2.271×10^{-6}	3.505×10^{-5}	3.647×10^{-6}	α
	12.658[b]		3.641×10^{-4}	5.698×10^{-4}	2.414×10^{-3}	4.423×10^{-5}	1.025×10^{-3}	1.045×10^{-4}	
	12.586[c]		9.445×10^{-4}	8.404×10^{-4}	3.470×10^{-3}	6.226×10^{-5}	1.509×10^{-3}	1.535×10^{-4}	
	13.549[d]		6.720×10^{-6}	5.968×10^{-6}	3.478×10^{-5}	8.375×10^{-7}	1.118×10^{-5}	1.172×10^{-6}	
$^{310}121$	11.865[a]	2.289×10^{-1}	7.505×10^{-3}	1.163×10^{-2}	4.288×10^{-2}	6.771×10^{-4}	1.927×10^{-2}	2.018×10^{-3}	α
	12.498[b]		3.296×10^{-4}	3.357×10^{-4}	1.580×10^{-3}	2.968×10^{-5}	5.703×10^{-4}	6.112×10^{-5}	
	12.564[c]		1.502×10^{-4}	2.355×10^{-4}	1.138×10^{-3}	2.179×10^{-5}	4.018×10^{-4}	4.316×10^{-5}	
	13.168[d]		6.542×10^{-6}	1.035×10^{-5}	6.246×10^{-5}	1.436×10^{-6}	1.819×10^{-5}	1.993×10^{-6}	
$^{306}119$	13.925[a]	3.528×10^{-5}	7.508×10^{-8}	7.565×10^{-8}	7.013×10^{-7}	2.257×10^{-8}	1.324×10^{-7}	1.574×10^{-8}	α
	13.234[b]		1.960×10^{-6}	1.960×10^{-6}	1.426×10^{-5}	3.634×10^{-7}	3.296×10^{-6}	3.832×10^{-7}	
	13.332[c]		1.183×10^{-6}	1.217×10^{-6}	9.151×10^{-6}	2.409×10^{-7}	2.053×10^{-6}	2.395×10^{-7}	
	12.616[d]		4.432×10^{-5}	4.469×10^{-5}	2.582×10^{-4}	5.429×10^{-6}	7.254×10^{-5}	8.258×10^{-6}	
^{302}Ts	12.745[a]	6.165×10^{-6}	5.804×10^{-6}	5.804×10^{-6}	4.122×10^{-5}	9.825×10^{-7}	9.026×10^{-6}	1.093×10^{-6}	α
	12.257[b]		5.917×10^{-5}	7.434×10^{-5}	4.394×10^{-4}	9.043×10^{-6}	1.130×10^{-4}	1.344×10^{-5}	
	12.247[c]		7.845×10^{-5}	7.845×10^{-5}	4.607×10^{-4}	9.456×10^{-6}	1.189×10^{-4}	1.414×10^{-5}	
	11.424[d]		8.278×10^{-3}	8.278×10^{-3}	3.489×10^{-2}	5.732×10^{-4}	1.209×10^{-2}	1.390×10^{-3}	
^{298}Mc	9.595[a]	1.498×10^{-6}	3.002×10^{2}	3.611×10^{2}	7.743×10^{2}	9.518	4.773×10^{2}	5.296×10^{1}	SF
	9.570[b]		3.631×10^{2}	4.365×10^{2}	9.252×10^{2}	1.133×10^{1}	5.774×10^{2}	6.397×10^{1}	
	9.567[c]		3.715×10^{2}	4.466×10^{2}	9.425×10^{2}	1.154×10^{1}	5.889×10^{2}	6.524×10^{1}	
	9.313[d]		2.677×10^{3}	3.202×10^{3}	5.962×10^{3}	7.053×10^{1}	4.230×10^{3}	4.617×10^{2}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

The universal curve of Poenaru *et al.* [69,70] for calculating the α-decay half-lives is derived by extending a fission theory to larger asymmetry. It is given by

$$\log_{10}T(s) = -\log_{10}P_S - \log_{10}S + [\log_{10}(\ln 2) - \log_{10}\nu], \qquad (22)$$

where T is the half-life, and ν, S, and P_S are three model dependent quantities. ν is the frequency of assaults on the barrier per second, S is the preformation probability of the cluster at the nuclear surface, and P_S is the quantum penetrability of the external potential barrier.

The penetrability of an external Coulomb barrier having the first turning point as the separation distance at the touching configuration $R_a = R_t = R_d + R_e$ and the second one defined by $e^2 Z_d Z_e / R_b = Q$ may be obtained analytically as

$$-\log_{10}P_S = 0.22873(\mu_A Z_d Z_e R_b)^{1/2} \times [\arccos\sqrt{r} - \sqrt{r(1-r)}], \qquad (23)$$

where $r = R_t/R_b$ fm, $R_t = 1.2249(A_d^{1/3} + A_e^{1/3})$ fm, and $R_b = 1.43998 Z_d Z_e / Q$ fm.

The decimal logarithm of the preformation factor is given as

$$\log_{10}S = -0.598(A_e - 1), \qquad (24)$$

and the additive constant for even-even nuclei is

$$c_{ee} = [-\log_{10}\nu + \log_{10}(\ln 2)] = -22.16917. \qquad (25)$$

By applying a fitting procedure on α emitters Royer [71] developed a formula for calculating the α-decay half-lives as follows:

$$\log_{10}[T_{1/2}(s)] = a + bA^{1/6}\sqrt{Z} + \frac{cZ}{\sqrt{Q_\alpha}}, \qquad (26)$$

where A and Z represent the mass and charge number of the parent nuclei and Q_α represents the energy released during the

TABLE XI. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for the isotopes $^{319,320}125$ and their decay products.

Parent nuclei	Q_α (MeV)	T_{SF} (s)	$T^{\alpha}_{1/2}$ (s) CPPMDN	CPPM	VSS	UNIV	Royer	UDL	Mode of decay
$^{319}125$	13.695[a]	4.226×10^{5}	9.580×10^{-6}	1.053×10^{-5}	2.562×10^{-5}	1.280×10^{-6}	5.131×10^{-6}	2.070×10^{-6}	α
	12.919[b]		4.909×10^{-4}	5.416×10^{-4}	1.006×10^{-3}	3.954×10^{-5}	2.008×10^{-4}	1.009×10^{-4}	
	13.062[c]		2.317×10^{-4}	2.554×10^{-4}	4.988×10^{-4}	2.045×10^{-5}	9.960×10^{-5}	4.800×10^{-5}	
	13.351[d]		5.266×10^{-5}	5.798×10^{-5}	1.254×10^{-4}	5.617×10^{-6}	2.508×10^{-5}	1.113×10^{-5}	
$^{315}123$	13.205[a]	1.281×10^{1}	3.539×10^{-5}	3.181×10^{-5}	7.729×10^{-5}	3.542×10^{-6}	1.446×10^{-5}	6.065×10^{-6}	α
	12.646[b]		6.511×10^{-4}	5.874×10^{-4}	1.166×10^{-3}	4.517×10^{-5}	2.180×10^{-4}	1.074×10^{-4}	
	12.568[c]		9.922×10^{-4}	8.956×10^{-4}	1.728×10^{-3}	6.547×10^{-5}	3.231×10^{-4}	1.630×10^{-4}	
	13.009[d]		9.624×10^{-5}	8.662×10^{-5}	1.961×10^{-4}	8.463×10^{-6}	3.670×10^{-5}	1.626×10^{-5}	
$^{311}121$	11.815[a]	2.459×10^{-3}	1.316×10^{-2}	1.505×10^{-2}	2.561×10^{-2}	8.467×10^{-4}	4.520×10^{-3}	2.599×10^{-3}	SF
	11.851[b]		1.066×10^{-2}	1.219×10^{-2}	2.102×10^{-2}	7.015×10^{-4}	3.710×10^{-3}	2.108×10^{-3}	
	11.875[c]		9.269×10^{-3}	1.061×10^{-2}	1.845×10^{-2}	6.197×10^{-4}	3.257×10^{-3}	1.837×10^{-3}	
	13.048[d]		1.585×10^{-5}	1.832×10^{-5}	4.978×10^{-5}	2.340×10^{-6}	8.763×10^{-6}	3.483×10^{-6}	
$^{320}125$	13.535[a]	7.749×10^{3}	1.334×10^{-5}	2.233×10^{-5}	1.169×10^{-4}	2.439×10^{-6}	4.338×10^{-5}	4.330×10^{-6}	α
	12.535[b]		2.482×10^{-3}	4.186×10^{-3}	1.533×10^{-2}	2.371×10^{-4}	7.810×10^{-3}	7.566×10^{-4}	
	12.709[c]		9.580×10^{-4}	1.613×10^{-3}	6.299×10^{-3}	1.023×10^{-4}	3.029×10^{-3}	2.951×10^{-4}	
	13.011[d]		1.918×10^{-4}	3.223×10^{-4}	1.406×10^{-3}	2.495×10^{-5}	6.135×10^{-4}	6.031×10^{-5}	
$^{316}123$	13.025[a]	2.265×10^{-1}	7.348×10^{-5}	7.712×10^{-5}	3.993×10^{-4}	7.607×10^{-6}	1.393×10^{-4}	1.447×10^{-5}	α
	12.488[b]		1.264×10^{-3}	1.340×10^{-3}	5.711×10^{-3}	9.289×10^{-5}	2.373×10^{-3}	2.423×10^{-4}	
	12.456[c]		1.506×10^{-3}	1.597×10^{-3}	6.704×10^{-3}	1.081×10^{-4}	2.814×10^{-3}	2.872×10^{-4}	
	12.759[d]		2.943×10^{-4}	3.104×10^{-4}	1.459×10^{-3}	2.566×10^{-5}	5.541×10^{-4}	5.710×10^{-5}	
$^{312}121$	11.735[a]	3.954×10^{-5}	2.599×10^{-2}	2.329×10^{-2}	8.730×10^{-2}	1.241×10^{-3}	3.802×10^{-2}	3.993×10^{-3}	SF
	11.726[b]		2.741×10^{-2}	2.457×10^{-2}	9.202×10^{-2}	1.305×10^{-3}	4.022×10^{-2}	4.223×10^{-3}	
	11.678[c]		3.643×10^{-2}	3.266×10^{-2}	1.195×10^{-1}	1.675×10^{-3}	5.315×10^{-2}	5.570×10^{-3}	
	12.688[d]		1.276×10^{-4}	1.140×10^{-4}	6.166×10^{-4}	1.141×10^{-5}	1.932×10^{-4}	2.100×10^{-5}	

[a] Q value calculated using the mass excess taken from the mass table of Moller *et al.* [51].
[b] Q value calculated using the mass excess taken from the WS4 mass table [63].
[c] Q value calculated using the mass excess taken from the WS3 mass table [64].
[d] Q value calculated using the mass excess taken from the mass table of Koura *et al.* [65].

reaction. The constants a, b, and c are

$$\left.\begin{array}{llllll} a=-25.31, & b=-1.1629, & c=1.5864 & \text{for} & Z=\text{even} & N=\text{even} \\ a=-26.65, & b=-1.0859, & c=1.5848 & \text{for} & Z=\text{even} & N=\text{odd} \\ a=-25.68, & b=-1.1423, & c=1.5920 & \text{for} & Z=\text{odd} & N=\text{even} \\ a=-29.48, & b=-1.1130, & c=1.6971 & \text{for} & Z=\text{odd} & N=\text{odd} \end{array}\right\}. \tag{27}$$

In the present work we have only used the analytical formulas for odd-even and odd-odd nuclei for calculating the α-decay half-lives.

The universal decay law (UDL) for α-decay and cluster decay modes introduced by Qi *et al.* [72,73] is given as

$$\log_{10}(T_{1/2}) = aZ_cZ_d\sqrt{\frac{A}{Q_c}} + b\sqrt{AZ_cZ_d\left(A_d^{1/3}+A_c^{1/3}\right)} + c \tag{28}$$

$$= a\chi' + b\rho' + c, \tag{29}$$

where $A = \frac{A_dA_c}{A_d+A_c}$ and the constants $a = 0.4314$, $b = -0.4087$, and $c = -25.7725$ are determined by fitting to experiments of both α and cluster decays [72]. The two parameters χ' and ρ' depend on the atomic and mass numbers of the daughter and emitted particles as well as the Q value.

The comparison of the α half-lives of the isotopes of $Z = 125$ within the range $310 \leqslant A \leqslant 320$ are given in Tables II–XI. It is seen that the predictions on the half-life values using different formalisms are in agreement with each other. The sensitivity of half-lives to the Q values is also clear from the table. A change in Q value about 1 MeV make about two order changes in half-lives.

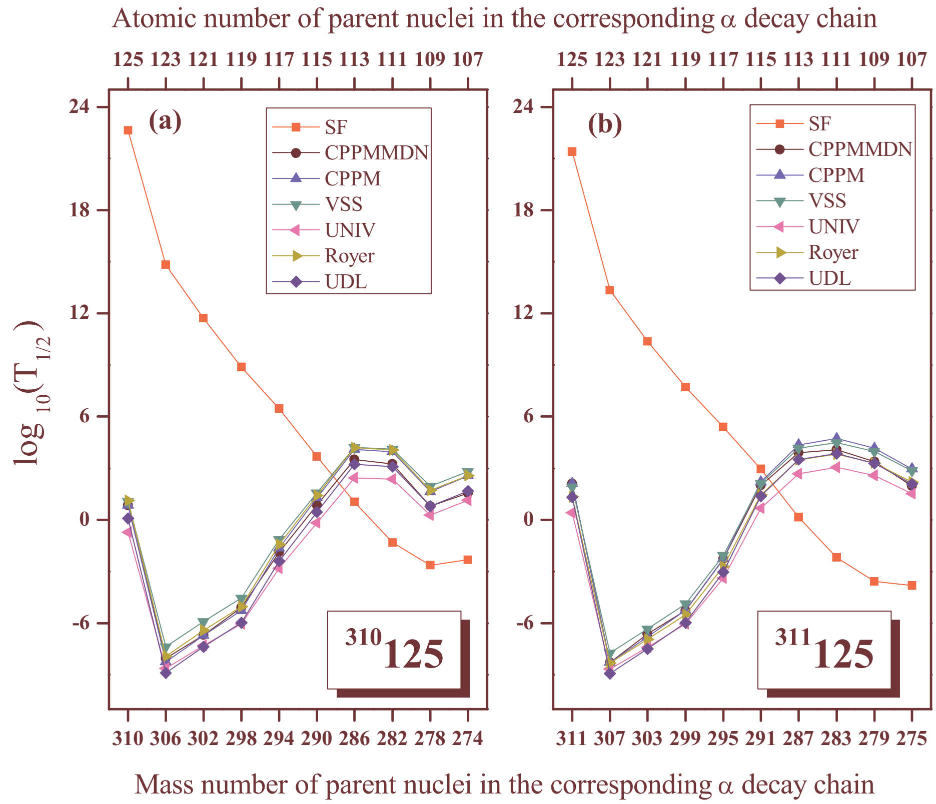

FIG. 1. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotopes $^{310,311}125$ and their decay products.

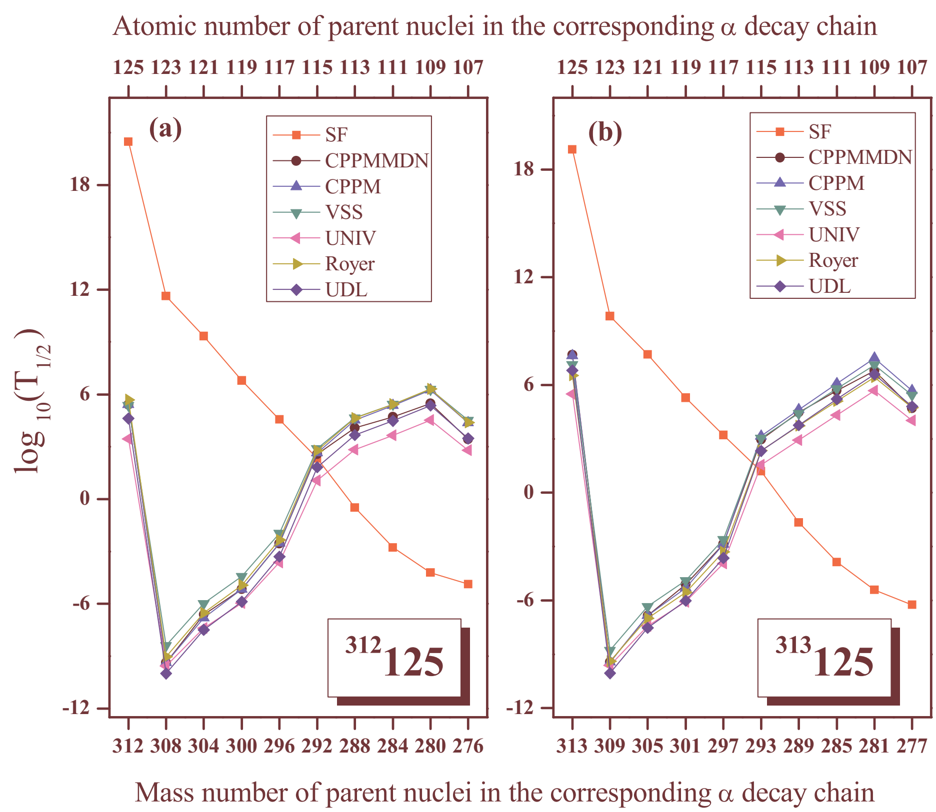

FIG. 2. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotopes $^{312,313}125$ and their decay products.

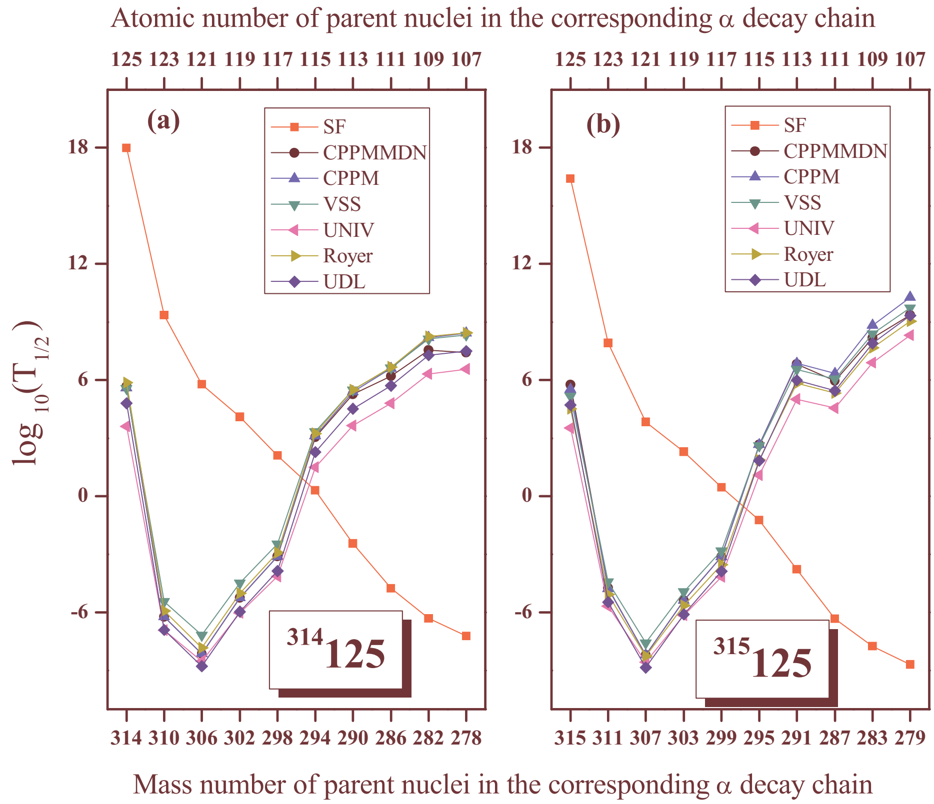

FIG. 3. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotopes $^{314,315}125$ and their decay products.

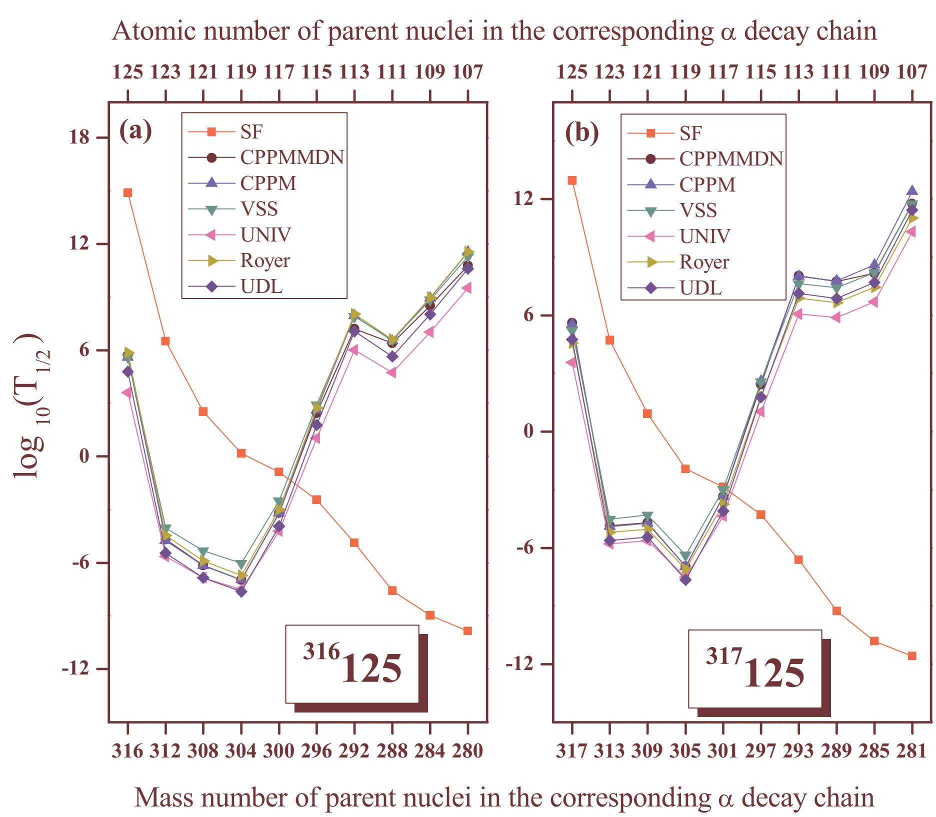

FIG. 4. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotopes $^{316,317}125$ and their decay products.

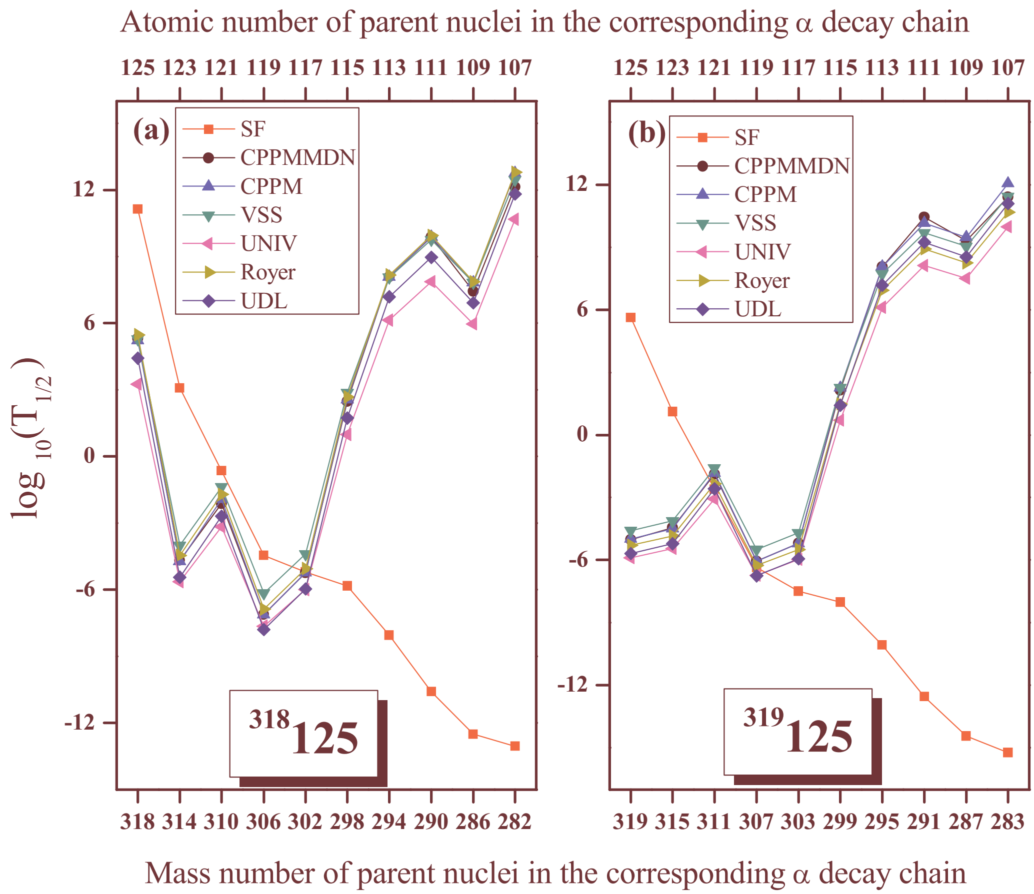

FIG. 5. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotopes $^{318,319}125$ and their decay products.

D. Spontaneous fission half-lives (T_{SF})

SF is one of the most prominent decay modes energetically feasible for heavy and SH nuclei. The fission as well as α decay probability determines the stability of SHN. Theoretically the quantum tunneling effect is considered as the underlying mechanism. The probability of tunneling through a potential barrier depends exponentially on the square root of the barrier height and is inversely related to the fissionability parameter. The fissionability parameter $\frac{Z^2}{A}$ and the isospin effect $I = \frac{N-Z}{N+Z}$ play an important role in determining the SF half-lives of heavy and SH nuclei. Considering these two factors our group had developed a semiempirical formula for calculating the SF half-lives in 2010 [36]. Since the shell structure also plays an important role in determining SF half-lives, by including the shell correction term, we modified the previous formula [74] as given below:

$$\log_{10}(T_{1/2}/yr) = a\frac{Z^2}{A} + b\left(\frac{Z^2}{A}\right)^2 + c\left(\frac{N-Z}{N+Z}\right) + d\left(\frac{N-Z}{N+Z}\right)^2 + eE_{\text{shell}} + f, \quad (30)$$

where $a = -43.25203$, $b = 0.49192$, $c = 3674.3927$, $d = -9360.6$, $e = 0.8930$, and $f = 578.56058$. E_{shell} is the shell correction energy taken from Ref. [51]. Here we would like to mention that the parameters used in Eq. (30) are obtained using a least square fit to the experimental data for SF.

The estimated standard deviation from the experimental SF half-life values of 45 nuclei is found to be 1.6972, i.e., the average deviation between the theoretical and experimental SF half-lives is less than 10^2 times. This level of agreement is very satisfactory since SF is a much more complex process than α decay.

E. α-decay chains of $Z = 125$

The α-decay chains of the isotopes of $Z = 125$ are predicted by comparing the α-decay half-lives (with Q values using the mass table of Moller *et al.* [51]) calculated using CPPMDN with the SF half-lives using the shell-effect-dependent formula. The nuclei with α-decay half-lives shorter than spontaneous fission half-lives will survive fission and hence decay through α emission. It was seen that isotopes $^{310-320}125$ and isotope $^{323}125$ exhibit an α-decay chain followed by SF. The isotopes $^{321,322}125$ and $^{324-339}125$ decay through SF. The α-decay chains of isotopes $^{310-320}125$ are given in Tables II–XI. Isotopes $^{310,311}125$ exhibit 6α chains whereas isotopes $^{312-318}125$ exhibit 5α chains. Isotopes $^{319,310}125$ show 2α chains followed by SF.

For few isotopes, a slight difference can be seen in the number of α-decay chains while using different Q values. For

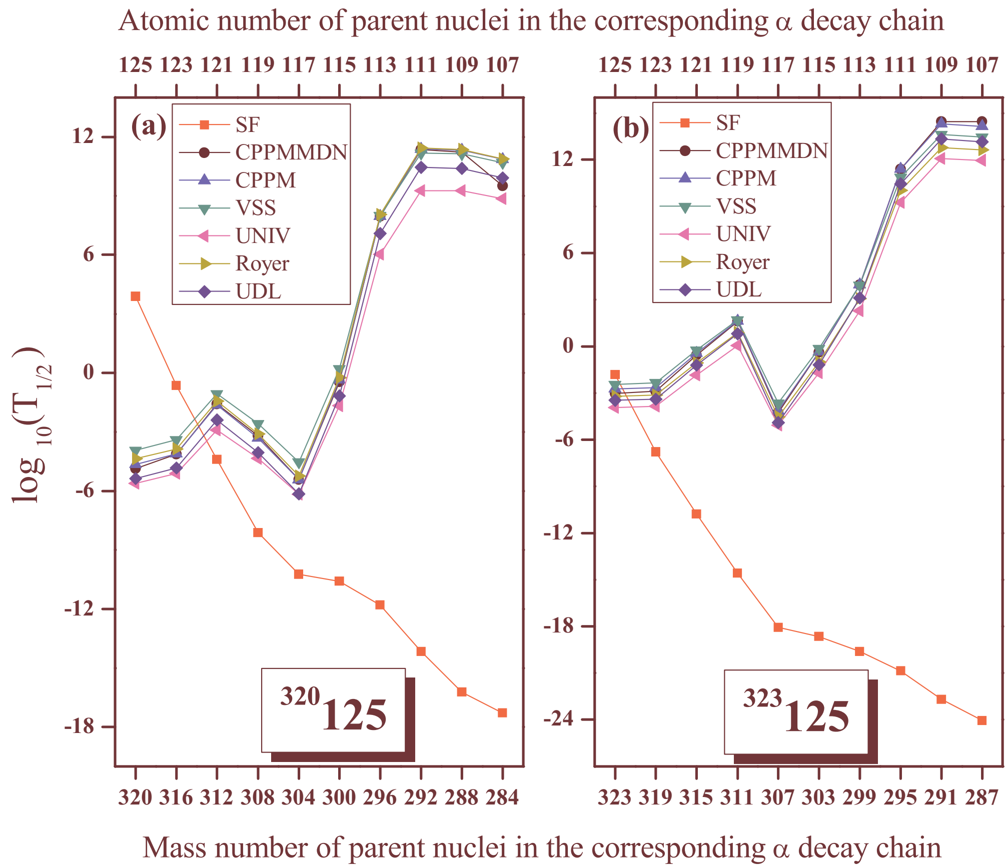

FIG. 6. The comparison of the calculated α-decay half-lives with the spontaneous fission half-lives for isotopes $^{320,323}125$ and their decay products.

example, isotope $^{312}125$ exhibit 5α chains if the mass table of Moller *et al.* [51] and Koura *et al.* [65] are used for the half-life calculation. But while using the WS4 [63] and WS3 [64] mass tables, it is seen that the isotope shows 6α chains.

A comparison of α-decay half-lives with SF half-lives for isotopes $^{310-320,323}125$ are given in Figs. 1–6. The matching between α half-lives calculated using different formalisms is clear from the figures. In Fig. 1, a dip can be seen at $N = 183$ for the α-decay curves which may appear to be due to the neutron shell closure at $N = 184$. But such an effect is not seen in the curve for SF. Here we have plotted $\log_{10}T_{1/2}$ versus the mass number of the parent nuclei in the corresponding α-decay chain, where the Z value is different for each parent nuclei. The shell effect can be clearly observed if we draw a plot of $\log_{10}T_{1/2}$ versus the mass (neutron) number of the parent for the isotopes with a given Z value.

IV. CONCLUSIONS

The α-decay chains of the isotopes of $Z = 125$ are predicted by comparing the α-decay half-lives calculated using CPPMDN with the spontaneous fission half-lives using the shell-effect-dependent formula. Four different mass tables are used for calculating the Q values for the decay. Six different theoretical formalisms are used for determining the α-decay half-lives. By estimating the proton separation energies, it is seen that isotopes $^{303-309}125$ may decay through proton emission. By comparing the α-decay half-lives with the spontaneous fission half-lives, isotopes $^{310,311}125$ show 6α chains. 5α chains can be seen from isotopes $^{312-318}125$. Isotopes $^{319,320}125$ exhibit 2α chains and $^{323}125$ exhibits 1α chain. All the other isotopes, that is, $^{321,322,324-339}125$, decay through spontaneous fission. We hope that the studies will be useful for future experimental investigations.

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