Alpha decay chains of superheavy nuclei $^{278,282}113$

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Introduction

Superheavy nuclei (SHN) and their decay studies is one of the fast developing fields in nuclear physics. Significant theoretical and experimental investigations have been made in the region of superheavy nuclei since the prediction of the existence of the magic island or island of stability. Recently, the isotopes of superheavy elements with Z=114-118 have been synthesized successfully through the hot and cold fusion reactions.

The $^{282}113$ nuclide has been synthesized through the ^{237}Np+^{48}Ca fusion reaction and its alpha decay chain has been observed [1]. Later on, the isotope $^{278}113$ was produced through ^{207}Np+^{70}Zn reaction with six consecutive α chains [2].

In the present paper, the alpha decay half lives of the recently synthesized $^{278,282}113$ isotopes has been studied within the Coulomb and proximity potential model for the deformed nuclei (CPPMDN) [3], and it is an extension of the previous works on the alpha decay half lives of Z=115, 117-120 [4]. The studies on the alpha decay and spontaneous fission (SF) of superheavy nuclei help to predict the mode of decay of these nuclei.

The Model

In CPPMDN, the interacting potential between the two deformed nuclei has been taken as the sum of the deformed Coulomb potential, deformed two-term proximity potential and the centrifugal potential for the touching configuration and for the separated fragments. The simple power law interpolation was used for the overlap region.

The Coulomb interaction between the two deformed and oriented nuclei is given as,

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

with

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

Here $R_{0i} = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3}$ where α_i is the angle between the radius vector and symmetry axis of the ith nuclei. The two-term proximity potential for the interaction between a deformed and spherical nucleus is given by Baltz et. al., as

$$V_{P2}(R,\theta) = 2\pi\left[\frac{R_1(\alpha)R_C}{R_1(\alpha)+R_C+S}\right]^{1/2}\left[\frac{R_2(\alpha)R_C}{R_2(\alpha)+R_C+S}\right]^{1/2} \times \left[\left[\varepsilon_0(S) + \frac{R_1(\alpha)+R_C}{2R_1(\alpha)R_C}\varepsilon_1(S)\right]\left[\varepsilon_0(S) + \frac{R_2(\alpha)+R_C}{2R_2(\alpha)R_C}\varepsilon_1(S)\right]\right]^{1/2} \tag{3}$$

where *R₁(α)* and *R₂(α)* are the principal radii of curvature of the daughter nuclei at the point where polar angle is α, *S* is the distance between the surfaces along the straight line connecting the fragments, R_C is the radius of the spherical cluster, $\varepsilon_0(S)$ and $\varepsilon_1(S)$ are the one dimensional slab-on-slab function. Using one dimensional WKB approximation, the barrier penetrability P is given as

$$\mathrm{P} = \exp\left\{-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}\,dz\right\} \tag{4}$$

The turning points "*a*" and "*b*" are determined from the equation, V(a)=V(b)=Q. The half life time is given by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\nu P}\right) \tag{5}$$

where, $\nu = (\omega/2\pi) = (2E_v/h)$, represents the number of assaults on the barrier per second and λ the decay constant. $E_{v,}$ is the empirical vibration energy.

Results and discussions

The alpha decay chains of $^{278,282}113$ have been studied using CPPMDN. The alpha half lives have also been calculated using the Coulomb and proximity potential model (CPPM) and the values have been compared with the

Viola-Seaborg semi-empirical relationship (VSS), the Universal curve (UNIV) of Poenaru et al., and the analytical formulae of Royer. In order to understand the mode of decay of isotopes, the SF half lives are evaluated by using the semi empirical relation of Xu *et al.*, given as

$$T_{1/2} = \exp\left\{2\pi\left[C_0 + C_1 A + C_2 Z^2 + C_3 Z^4 + C_4 (N-Z)^2 - (0.13323\frac{Z^2}{A^{1/3}} - 11.64)\right]\right\} \qquad (6)$$

Now, by comparing the alpha decay half lives with the spontaneous fission half lives we can identify the nuclei that will survive fission. Among these, the isotopes with alpha decay half lives smaller than the spontaneous fission half lives can survive fission and hence can be detected in the laboratory.

The studies on the alpha decay half lives of the experimentally synthesized ^{278}113 and ^{282}113 isotopes have been shown in Table 1 and Table 2 respectively. In column 2 of the tables the SF half lives of the isotopes under study, evaluated using the phenomenological formula of Xu *et al.* is given, while column 3 gives the comparison of the present values with the experimental α decay half lives [1, 2]. Experimental Q values have been used for the evaluation of the α half lives using CPPMDN and the ground state quadrupole (β_2) and hexadecapole (β_4) deformation of both the parent and the daughter nuclei are included.

Table 1. The comparison of the calculated alpha decay half lives with the spontaneous fission half lives for the isotopes ^{278}113.

Parent Nuclei	T_{SF} (s)	$T^{\alpha}_{1/2}$	
		Expt.	CPPMDN
^{278}113	3.83x10^{1}	0.667ms	$0.02^{-0.01}_{+0.01}$ ms
^{274}111	2.85x10^{-1}	9.97ms	$1.94^{-0.89}_{+0.61}$ ms
^{270}Mt	4.69x10^{-2}	444ms	$19.75^{-11.40}_{+18.49}$ ms
^{266}Bh	1.81x10^{-1}	5.26s	$0.06^{-0.03}_{+0.02}$ s
^{262}Db	6.94x10^{0}	126s	$1.34^{-0.89}_{+0.51}$ s
^{258}Lr	1.60x10^{3}	3.78s	$0.07^{-0.05}_{+0.03}$ s

From Table 1, it can be seen that, the computed alpha decay half lives of ^{278}113 matches well with the experimental values. On comparing the SF half lives with the alpha decay half lives we can also predict a 6α chain from ^{278}113, which agrees well with the experimental observation. Experimentally, it has been shown that, after the 6th α chain, the isotope ^{254}Md shows electron capture ($b_{\varepsilon} \approx 100\%$) and thereafter, the daughter isotope, ^{254}Fm, will undergo alpha decay. The same result has been predicted within CPPMDN.

From the Table 2, it can be clearly seen that, the alpha decay half lives computed within CPPMDN for ^{282}113 closely agrees with the experimental values and on comparing the spontaneous fission half lives with the alpha decay half lives, we can predict 3α chain from the isotope.

Thus, our study reveals that, even though there is a one order difference in alpha decay half lives for some of the isotopes under study, the predictions on the decay modes and the alpha decay half lives of ^{278}113 and ^{282}113 go hand in hand with the experimental results.

Table 2. The comparison of the calculated alpha decay half lives with the spontaneous fission half lives for the isotopes ^{282}113 and its decay products.

Parent Nuclei	T_{SF} (s)	$T^{\alpha}_{1/2}$	
		Expt	CPPMDN
^{282}113	5.67x10^{1}	88.9ms	$19.6^{-7.79}_{+13.15}$ ms
^{278}111	3.47x10^{-1}	6.2ms	$2.7^{-1.03}_{+1.72}$ ms
^{274}Mt	2.79x10^{-2}	472.6ms	$20.5^{-20.47}_{+5.5E4}$ ms
^{270}Bh	3.54x10^{-2}	87.98s	$5.5^{-2.56}_{+4.84}$ s

References

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