Alpha Decay Chains of ^{294}Og within an Improved Coulomb and Proximity Potential Model

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Introduction

In the second decade of the 20th century, Rutherford and Geiger made the observation of alpha decay. Alpha decay is the most important tool for probing various nuclear characteristics such as radii, unstable nuclei's half-lives, spin and parity, energy released, nuclear deformations, and shell effects. The alpha particle is assumed to be preformed inside the nucleus which tunnels through the nuclear potential barrier and eventually escapes from the nucleus. Superheavy elements which are synthesized through cold and hot fusion reactions are identified by observing their alpha decay chains. Within the superheavy nuclei region, alpha decay and spontaneous fission are the predominant decay modes.

The last superheavy isotope synthesized is ^{294}Og (Z = 118) through the bombardment of ^{48}Ca on a Cf target at the Flerov Laboratory of Nuclear Reactions (FLNR) in Dubna, Russia. Since then, various theoretical studies have been reported on the decay characteristics of ^{294}Og based on many theoretical and empirical models. In the present study, we analyze the alpha decay chains of the experimentally synthesized superheavy isotope ^{294}Og by using an improved Coulomb and Proximity Potential Model (CPPM) by calculating the Q-value by using different mass tables.

Improved Coulomb and Proximity Potential Model

The coulomb and Proximity Potential Model is improved by Prathapan et al. [1] by inputting a more accurate expression for the diffuseness parameter in the proximity potential. In the CPPM, the interaction potential barrier is the sum of Coulomb, proximity, and centrifugal potentials for the touching configuration and for the separated fragments. For the overlap region, we use a simple power law interpolation as provided by Y.J. Shi and W.J. Swiatecki [2] in 1985. For a parent nucleus exhibiting exotic decay, the interacting potential barrier can be written as;

$$V = \frac{Z_1 Z_2 e^2}{r} + V_p(z) + \frac{\hbar^2 l(l+1)}{2\mu r^2} \text{ ; for } z > 0 \qquad (1)$$

where Z_1 and Z_2 are the atomic numbers of the daughter and the emitted cluster, r is the distance between the fragment centers, l is the angular momentum quantum number, μ is the reduced mass, and $V_p(z)$ is the proximity potential given by Blocki et al [3].

$$V_p(z) = 4\pi\gamma b\left[\frac{C_1 C_2}{(C_1 + C_2)}\right]\Phi\left(\frac{z}{b}\right) \qquad (2)$$

where γ is the surface tension coefficient, b is the width of the nuclear surface (diffuseness), C_i are Süssmann central radii, and Φ is the universal proximity potential. These equations are applied to spherical nuclei. In earlier studies using the CPPM, the diffuseness parameter is taken as $1 fm$ which causes an underestimation of decay half-lives. The diffuseness parameter is given by the empirical expression [4],

$$b = \frac{\pi}{\sqrt{3}}\left(0.0030511Z - 0.001501N\right)Q^{1/2} + 0.15455 \qquad (3)$$

The barrier penetrability P can be obtained by using one-dimensional WKB approximation and is given as;

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

where a and b are the turning points given by, $V(a) = V(b) = Q$.

This integral can be evaluated numerically or analytically to get the half-life time of decay as;

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

where, $\nu = \frac{\omega}{2\pi} = \frac{2E_V}{h}$, the number of assaults on the barrier per second and E_V is the empirical zero-point vibration energy.

Results and Discussions

The alpha decay chain of ^{294}Og superheavy nucleus is studied within the improved CPPM. The alpha decay half-lives are calculated by inputting the experimental alpha decay energy and the Q-values are calculated using the WS4, KTUY, FRDM, and TCSM mass tables with an aim to identify the most suitable mass table for the Q-values of alpha emission in superheavy region. The results of our calculations are given in Table 1.

Table 1: Q-values corresponding to the alpha decay chains of ^{294}Og calculated using various mass models.

Parent	*Q*- Value (*MeV*)				
	Exp.[5]	WS4	KTUY	FRDM	TCSM
^{294}Og	11.82	12.19	11.16	12.28	11.53
^{290}Lv	11.00	11.12	10.58	11.12	10.89
^{286}Fl	10.35	10.38	9.73	9.39	10.38
^{282}Cn	……	10.15	10.13	9.41	10.54
^{278}Ds	……	10.26	10.13	10.41	10.03

From the calculated Q-values given in the table, one can see that the Q-values estimated using the WS4 and TCSM models are very close to the experimental values for ^{294}Og than the values predicted by the KTUY and FRDM models. This is in accordance with the findings of Sobiczewski [5]. However, one can notice that the WS4 model overestimates the Q values of ^{294}Og and its decay product ^{290}Lv. Also, the TCSM calculations underestimate the Q values for the same isotopes.

Table 2: The alpha decay chains of ^{294}Og calculated using the improved CPPM with Q values from Table 1

Parent	$\log_{10} T_{1/2}$(sec) (CPPM)				
	Exp. [5]	WS4	KTUY	FRDM	TCSM
^{294}Og	-3.16	-3.29	-0.72	-3.50	-1.68
^{290}Lv	-2.08	-1.25	0.22	-1.26	-0.63
^{286}Fl	-0.69	0.12	2.08	3.18	0.12
^{282}Cn	…..	0.11	0.16	2.39	-1.00
^{278}Ds	…..	0.89	-0.52	-1.31	-0.23

The alpha decay chain of ^{294}Og calculated within the improved CPPM by inputting the Q-values presented in Table 1 is given in Table 2 and is plotted in Fig. 1. The alpha decay half-lives are estimated by imputing the experimental Q-value and then by inputting the Q-values obtained by using the WS4, KTUY, FRDM, and TCSM models. From the table, it is clear that the alpha decay half-life is highly sensitive to the Q-value. For ^{294}Og, the Q-values of alpha decay calculated using the WS4 and TCSM models differ by 0.66 and it causes a change in the decay half-life by two orders of magnitude.

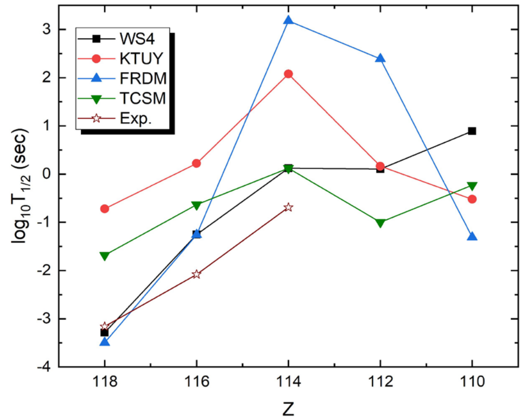

Fig.1: Logarithmic value of the α-decay half-lives calculated using CPPM with the Q-values estimated using various mass models compared with experimental data.

The decay mods are given in Table 3. From the table, it is clear that the WS4 and TCSM calculations within the improved CPPM predict three alpha decay chains for ^{294}Og. The KTUY and FRDM calculations predict two alpha decay chains for ^{294}Og.

Table 3: Decay modes of alpha decay chains of ^{294}Og for WS4, KTUY, FRDM, and TCSM calculations.

Parent	$\log_{10} T_{1/2}^{SF}$ [5]	Decay Mode			
		WS4	KTUY	FRDM	TCSM
^{294}Og	3.11	α	α	α	α
^{290}Lv	2.87	α	α	α	α
^{286}Fl	0.18	α	SF	SF	α
^{282}Cn	-0.15	SF	SF	SF	SF
^{278}Ds	-3.24	SF	SF	SF	SF

References

[1] K. Prathapan et al. Phys. Scr. **99** 035304 (2024).
[2] Y. J. Shi and W. J. Swiatecki Nucl. Phys. A, **438**, 450 (1985).
[3] J. Blocki and W. J. Swiatecki, Ann. Phys. (N.Y.) **132**, 53 (1981).
[4] K. Prathapan et al. Proc. Symp. Nucl. Phys. **67** 699 (2023).
[5] A. Sobiczewski, Phys. Rev. C **94**, 051302(R) (2016).
[6] A. Sobiczewski, J. Phys. G: Nucl. Part. Phys. **43** 095106 (2016).