Feasibility of alpha decay in $^{276\text{-}308}$119 superheavy nuclei

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Introduction

The heaviest element known so far is Z = 118 and any further progress in the synthesis of new elements with Z > 118 is not quite evident. The synthesis and identification of new elements remains a hot topic in nuclear physics as the question on the border of the elements' existence is still unanswered.

As the alpha decay properties and the mode of decay of both Z = 115 and Z = 117 have already been analyzed using our models, we were confident to carry out the alpha decay studies on the SHE Z = 119. Thus these theoretical predictions on Z = 119, the most hopeful new element with Z >118 to be synthesized in the near future, along with our earlier works, ensures the validity of our models.

The Coulomb and Proximity Potential Model for Deformed Nuclei

The potential energy barrier in CPPMDN is taken as the sum of deformed Coulomb potential, deformed two-term proximity potential and the centrifugal potential, for the touching configuration and for the separated fragments. For the pre-scission region, simple power law interpolation was used.

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

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

with (1)

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

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 interaction between a deformed and spherical nucleus is given by Baltz et. al., as

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

Here $R_1(\alpha)$ and $R_2(\alpha)$ 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

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

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

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

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

Results and Discussions

The study on the feasibility of alpha decay in the range 276 ≤ A ≤ 308 with Z = 119 have been done by evaluating the alpha half lives of these nuclei within CPPMDN [1]. The energy released in the alpha transitions between the ground state energy levels of the parent nuclei and the ground state energy levels of the daughter nuclei is given as

$$Q_{gs\to gs} = \Delta M_p - (\Delta M_\alpha + \Delta M_d) + k(Z_p^\varepsilon - Z_d^\varepsilon) \quad (6)$$

where ΔM_p, ΔM_d, ΔM_α are the mass excess of the parent, daughter and alpha particle respectively. The *Q* values are evaluated using the mass excess values taken from Wang et al., and Koura-Tachibana-Uno-Yamada (KTUY).

The term kZ^{ϵ} describes the screening effect of atomic electrons.

The CPPM formalism and the Viola-Seborg semi-empirical relationship (VSS) for alpha half lives have also been used for the half life calculations. The Viola-Seborg semi-empirical relationship is given as,

$$\log_{10}(T_{1/2}) = (aZ+b)Q^{-1/2} + cZ + d + h_{\log} \qquad (7)$$

Now the spontaneous fission (SF) half lives are evaluated so as to identify the mode of decay of the isotopes under study using the semi empirical relation of Xu *et al.*, given as

$$T_{1/2} = \exp\left\{2\pi\left[C_0 + C_1A + C_2Z^2 + C_3Z^4 + C_4(N-Z)^2 - \left(0.13323\frac{Z^2}{A^{1/3}} - 11.64\right)\right]\right\}$$

This equation was originally made to fit the even-even nuclei and in this work, as we have considered only the odd Z (odd - even and odd - odd) nuclei, instead of taking spontaneous fission half life T_{sf} directly, we have taken the average of fission half life T_{sf}^{av} of the corresponding neighboring even-even nuclei as the case may be. It is to be noted here that, in the case of the nuclei ^{259}Md, $T_{sf}^{\exp}$ = 5.760x10^{3}s and T_{sf}^{av} = 9.044x10^{3}s, which shows the agreement between experimental and computed average spontaneous fission half lives. As the isotopes with small alpha decay half lives than spontaneous fission half lives survive fission and thus can be detected through alpha decay in the laboratory, the comparison of the alpha decay half lives with the spontaneous fission half lives will enable us to identify the nuclei (both parent and decay products) that will survive fission.

As no experimental evidence exists regarding the production of any isotopes of Z = 119, we have done a detailed study on all the available isotopes from 274 ≤ A ≤ 313. Thus we have predicted the α decay half lives of 40 superheavy elements, focusing on the isotopes $^{276-308}$119, with a view to find possible alpha decay chains which may open up a new line in experimental investigations. The experimental spontaneous fission half lives have also been given in these plots. Our study reveals that those isotopes of Z 119 with A ≥ 309 and with A ≤ 275, do not survive fission and thus the alpha decay is restricted within the range 276 ≤ A ≤ 308. The highlighting facts of our work are presented in the figure 1 and 2.

Through our study, we have predicted 1α chain from $^{276,277,304-308}$119, 2α chains from $^{278,279,300-303}$119, 3α chains from ^{280,281,298,299}119, 4α chains from ^{296,297}119 and 6α chains from $^{292-295}$119. As our study predicts 6α chains consistently from $^{292-295}$119 and 4α chains consistently from ^{296,297}119, we hope that these findings will provide a new guide for future experiments.

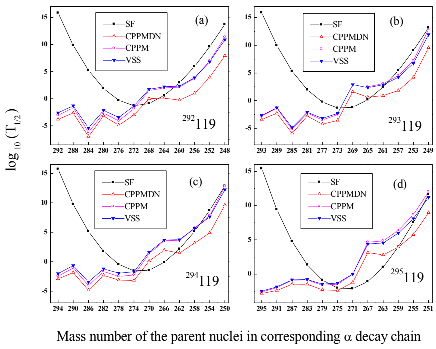

Fig.1. The comparison of the calculated alpha decay half lives with the spontaneous fission half lives for the isotopes $^{292-295}$119 and its decay products.

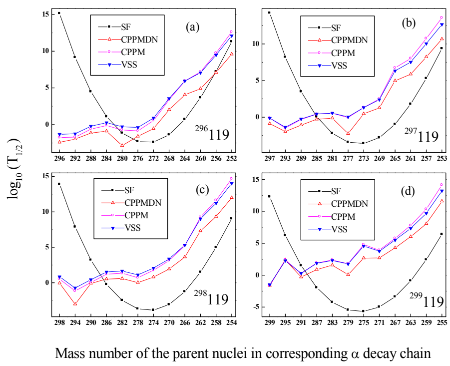

Fig.2. The comparison of the calculated alpha decay half lives with the spontaneous fission half lives for the isotopes $^{296-299}$119 and its decay products.

References

[1] K. P. Santhosh, S. Sabina and G. J. Jayesh, Nucl. Phys.**A 850**, 34 (2011).