Alpha radioactivity in $^{287\text{-}288}$115 super heavy nuclei

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Introduction

The discovery of α radioactivity by Rutherford and later on Gamow's theory gave a basis to successfully explain the experimental half lives using both phenomenological and microscopic models. The rapid progress in the experimental studies of the α decay of the super heavy nuclei (SHN) has resulted in the observation of many alternative α emitters in the super heavy region. An investigation of the α decay chains of the SHN is the main tool to obtain the information regarding their degree of stability and existence in nature. Even though several theoretical works can be quoted to the α decay studies of super heavy nuclei, works on odd mass nuclei are very rare.

The purpose of this paper is to study the α decay and the spontaneous fission of the isotopes of the super heavy element Z = 115 and predict the α decay chains using Coulomb and proximity potential model for deformed nuclei (CPPMDN) [1]. This model is the modified version of Coulomb and proximity potential model (CPPM) by incorporating the ground state deformations β_2 and β_4 of the parent and daughter but treating the cluster as a sphere. The success and applicability of CPPMDN in predicting the α decay half lives of the heavy and SHN have been revealed in our previous works by comparison with the experimental data.

The Coulomb and proximity potential model for deformed nuclei

In CPPMDN, the potential energy barrier is taken as the sum of deformed Coulomb potential, deformed two-term proximity potential and centrifugal potential for the touching configuration and for the separated fragments. For the pre-scission region, simple power law interpolation was used. The inclusion of proximity potential reduces the height of the potential barrier, which closely agrees with the experimental result.

The interacting potential barrier for two spherical nuclei is given by

$$V = \frac{Z_1 Z_2 e^2}{r} + V_p(z) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2}$$

Here Z_1 and Z_2 are the atomic numbers of the daughter and emitted cluster, 'z' is the distance between the near surfaces of the fragments, 'r' is the distance between fragment centers, ℓ represents the angular momentum, μ the reduced mass, V_P is the proximity potential given by Blocki *et al.*,

Using one dimensional WKB approximation, the barrier penetrability P is given as

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

The turning points "a" and "b" are determined from the equation, V(a)=V(b)=Q.

The half life time is given by

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

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 discussion

Using CPPMDN, we have calculated the alpha decay half lives of the recently synthesized super heavy elements, ^{287}115 and ^{288}115. 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

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

where ΔM_p, ΔM_d, ΔM_α are the mass excess of the parent, daughter and alpha particle respectively. The Q value is calculated using the experimental mass excess values taken from Audi *et al*., The term kZ^{ε} describes the screening effect of atomic electrons.

The alpha decay half lives of $^{287}115$ and $^{288}115$ and their decay products are evaluated within CPPMDN formalism. The half life calculations are also done using the Viola-Seborg semi-empirical relationship (VSS) for alpha half lives and is given as

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

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

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

As this equation was originally made to fit the even-even nuclei, and as we have considered only the odd mass (odd-even and odd-odd) nuclei in this work, 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. Here we would like to mention that, in the case of the nuclei ^{257}Lr, T_{sf}^{exp}=1.98x10^3s and T_{sf}^{av}=1.67x10^3s, which shows the agreement between experimental and computed average spontaneous fission half lives. The spontaneous fission half lives are calculated because isotopes with small alpha decay half lives than spontaneous fission half lives survive fission and can be detected through alpha decay in the laboratory. Now by comparing the alpha decay half lives with the spontaneous fission half lives we could identify the nuclei (both parent and decay products) that will survive fission. Thus we predict 4α chains to be seen for $^{287}115$ and 3α chains for $^{288}115$. As one may notice, our prediction agrees well with the experimental observations. It is also to be noted that the alpha half lives calculated using our formalisms matches well with the experimental alpha half lives. For eg: in the case of the nuclei $^{287}115$, $T_{1/2}^{exp}$=32ms and $T_{1/2}^{calc}$=48.77ms.

The entire work is presented in Figure 1. These figures give the plots for $log_{10}(T_{1/2})$ against the mass of the nuclei in the corresponding alpha chain. Here we have plotted alpha decay half lives calculated using the CPPM and CPPMDN formalisms. The alpha half lives are found to be decreasing when the deformation values are included as it is clear from the plots. It is clear from these figures that the values calculated using our formalisms matches well with the VSS values, values reported by GLDM and UMADAC with a few order differences in some cases. As we were successful in reproducing the experimental results in the case of $^{287}115$ and $^{288}115$, we have confidently extended our work in predicting the α decay half lives of 22 super heavy elements ranging from 271 ≤ A ≤ 294 of the same element with a view to find possible alpha decay chains which may open up a new line in experimental investigations.

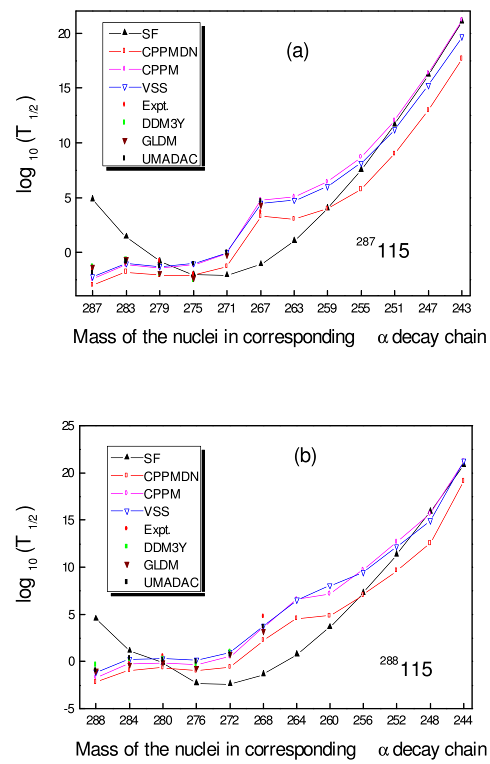

Fig. 1 The comparison of the calculated alpha decay half lives with the spontaneous fission half lives for the isotopes $^{287,\ 288}115$ and its decay products.

References

[1] K. P. Santhosh, Sabina Sahadevan and Jayesh George Joseph, Nucl. Phys. **A 850**, 34 (2011).