Probable cluster decays from $^{298\text{-}336}126$ superheavy nuclei

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Introduction

A general understanding on the nuclear reactions and properties, and on nuclear structure, in particular has been accelerated greatly through the various radioactive decay studies. Cluster radioactivity/heavy particle radioactivity is an intermediate process between alpha decay and nuclear fission, where a charged particle, heavier than ^{4}He but lighter than a fission fragment, is spontaneously emitted from an atomic nucleus. Even though the process of cluster radioactivity was predicted as an exotic decay mode by Sandulescu et al., in 1980, such a decay was first observed experimentally by Rose and Jones in 1984, in the radioactive decay of ^{223}Ra by the emission of ^{14}C. During last three decades, a whole family of such clusters ranging from ^{12}C to ^{50}Ca has either been observed or indicated as possible decay modes from various parent nuclei, with the half lives within the experimental upper limits.

In the present manuscript, as an extension to our earlier works [1, 2], we have done an extensive study on the various clusters that could be emitted from the isotopes of superheavy (SH) nuclei with Z=126. Several theoretical predictions, on the shell closures in the SH mass region, has been done at Z=114, 120, 126 and N=162, 172, 184. The present paper deals with an investigation on the cluster decay of even clusters ^{4}He, ^{8,10}Be, ^{14}C, ^{18,20,22}O, ^{22,24,26}Ne, ^{28,30}Mg and odd clusters ^{15}N, ^{23}F, ^{25}Ne, ^{29}Mg from both the even-even and even-odd isotopes of Z = 126, which has helped in predicting the neutron magicity beyond N = 126.

The Model

The Coulomb and proximity potential model (CPPM) has been used for the present study, where the potential energy barrier is taken as the sum of Coulomb potential, 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 interacting potential barrier for two spherical nuclei is given by

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

were 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

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

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

The half life time is given by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\upsilon P}\right) \qquad (3)$$

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 cluster decay process in $^{298\text{-}336}126$ superheavy nuclei has been studied extensively within the Coulomb and proximity potential model (CPPM), thereby investigating the probable cluster decays from the various isotopes of Z=126, which helps in predicting the magic island around N=184. The decay energy of the reaction is given as

$$Q = \Delta M_p - (\Delta M_\alpha + \Delta M_d) \qquad (4)$$

Here ΔM_p, ΔM_d, ΔM_α are the mass excess of the parent, daughter and cluster respectively.

The $T_{1/2}$ values for the respective cluster decays have also been calculated using the Universal (UNIV) curve [3] and the Universal decay law (UDL) [4] for alpha and cluster decay modes and the Scaling Law of Horoi et al., [5] for cluster decay and has been compared with the CPPM values.

The plots for $\log_{10}(T_{1/2})$ against the neutron number of the daughter nuclei for the emission of even clusters ^{4}He, ^{8,10}Be, ^{14}C and odd clusters ^{15}N, ^{23}F, ^{25}Ne, ^{29}Mg has been shown in Figure 1 and 2 respectively. The cluster decay half lives evaluated using other theoretical models has also been plotted in these figures. The figure 1 (a) gives the plot for the ^{4}He emission from the $^{298\text{-}336}$126 isotopes. Here the minima of the logarithmic half lives can be found for the decay around the daughter nuclei with N = 184. From the figure 1 (b) and (c) the minima of the logarithmic half lives can be clearly seen for the decay leading to the daughter nuclei ^{306}122 (N=184), and in figure 1 (d), the minima can be found for the decay leading to the daughter nuclei ^{304}120 (N = 184).

Usually, for the cluster emission of odd clusters from parent nuclei, the odd-even staggering (OES) effects are found to be predominant. The abrupt changes in binding energy as one goes from a nucleus with an even number of neutrons (or protons) to its neighbour with an odd number of nucleons are known as odd-even-stagger (OES), which can be attributed to the existence of nucleonic pairing correlations.

From the figure 2 (c) and (d), for the emission of odd clusters ^{25}Ne and ^{29}Mg from $^{298\text{-}336}$126, the OES can be seen predominantly, than for the emission of ^{15}N and ^{23}F in figure 2(a) and (b). From these observations, it is evident that OES becomes more and more dominant when the emitted clusters are heavy. From these figures also, the minima of the logarithmic half lives can be seen around N=184. The figures also show that the half lives evaluated within CPPM, match well over a wide range with the corresponding values evaluated using UNIV, UDL and the scaling law of Horoi.

Thus, for most of the decays, the half life is minimum for the decay leading to a daughter with or around N=184. Hence, our study reveals the fact that, the role of neutron shell closure is crucial than proton shell closure. As most of the predicted half-lives are well within the present upper limit for measurements, the predictions on the cluster decay half-lives of Z=126, performed within CPPM, may be of great use for further experimental investigation on cluster decay in the superheavy region.

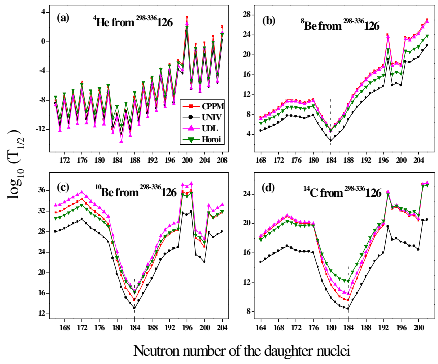

Fig.1. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{4}He, ^{8,10}Be and ^{14}C from $^{298\text{-}336}$126 SHN.

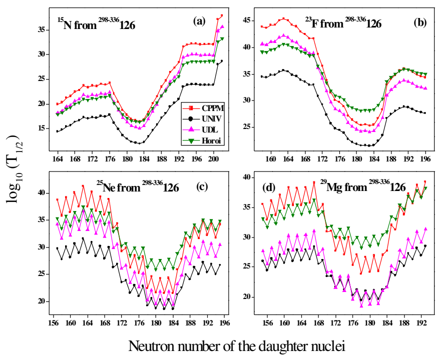

Fig.2. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{15}N, ^{23}F, ^{25}Ne and ^{29}Mg from $^{298\text{-}336}$126 SHN.

References

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