Analysis of α- and cluster-emission in superheavy nuclei

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Introduction

The studies on the competition of α- and cluster-emission in the region of superheavy nuclei (SHN) have been exploited extensively to understand the dynamical behavior in the extreme mass region of Periodic table. Such investigations provide valuable information regarding the nuclear structure and decay mechanisms. Most of the SHN decay primarily through consecutive α-emissions and eventually settle via fission of the residual nucleus. Hence, identifying and characterizing α-decay chains act as a decisive factor for the identification and degree of stability of the nuclide.

In a very recent work [1], some of us carried out a systematic study of α-decay half-lives for various isotopes of Z=113 to 118 SHN within the framework of preformed cluster model (PCM), where temperature T-effects were included for the first time via recoil energy of the residual SHN left after x-neutron emission from the compound system. This study indicated that PCM(T≠0)-calculated α-decay half-lives match the measured data nearly exactly, without using any scaling factor of type used in standard PCM(T=0) for spontaneous decays. It was observed [2] that the PCM(T=0)-calculated half-lives for the α-decay chains of $^{289,288,287}115$ required a constant scaling factor of 10^4 to match the experimental data. Thus, it will be interesting to explore the possible branching of α versus most probable cluster decay(s), with a view to identify the magic or near magic daughter(s) in the process of exotic cluster emission.

Therefore, in the present contribution, we take up this study of using PCM(T≠0) to analyze the competition of already studied α-decay [1] with other possible cluster emissions for each of the parent in the measured [3] α-decay chain of $^{294}118^*$, formed via ^{249}Cf + ^{48}Ca reaction after the $3n$ emission.

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The Model

In PCM(T≠0), the clusters are assumed to pre-born in the parent nucleus with a certain preformation probability P_0. The decay constant λ or half-life time $T_{1/2}$ is defined as,

$$\lambda = \nu_0 P_0 P, \qquad T_{1/2} = ln2/\lambda. \qquad (1)$$

The clusters hit the barrier with impinging frequency ν_0, and penetrate it with penetrability P. For α-decay of recoiled SHN, the temperature T is related to its excitation energy E^*_R,

$$E^*_R = \frac{A}{11}T^2 - T \qquad \text{(T in MeV)} \qquad (2)$$

where $E^*_R = E_R + Q_\alpha$. Here, Q_α denotes the Q-value of α-decay, and for the implantation (or recoil) energy E_R, we take the value 12.5 MeV, chosen in reference to the average of the measured [3] E_R range (7-18 MeV) for α-decay chains of $^{294}118^*$ compound nucleus.

Calculations and discussion

Fig. 1 gives the PCM(T≠0)-calculated preformation probability P_0, barrier penetrability P, and decay half-life $T_{1/2}$ for α-decay and most preferred clusters emitted from $^{294}118^*$ and its subsequent $^{290}116^*$ and $^{286}114^*$ residual parents occurring in the α-decay chain. We notice that the calculated $T^{\alpha}_{1/2}$ agree nicely with experimental data, which in turn gives a confidence that our model may impart a reasonable estimate of the possible emitted clusters. The calculations are made at the best fitted neck-length ΔR (given in figure caption)

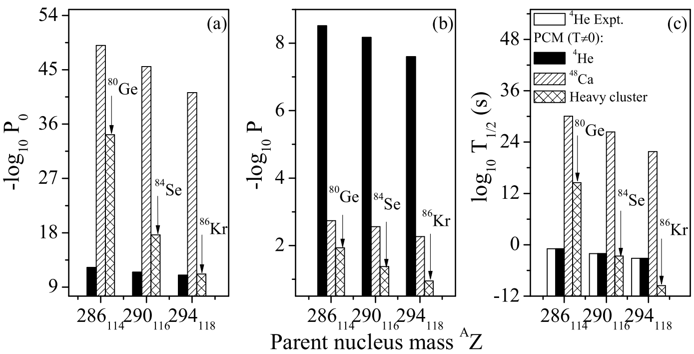

FIG. 1: Calculated (a) preformation probability P_0, (b) penetrability P, and (c) decay half-lives $T_{1/2}$ for α and most favorable cluster decays of parents occurring in α-decay chain of $^{294}118^*$. For best fit to α-decay data, ΔR values are, respectively, 0.976, 0.950, 0.941 fm for $^{294}118^*$, $^{290}116^*$ and $^{286}114^*$.

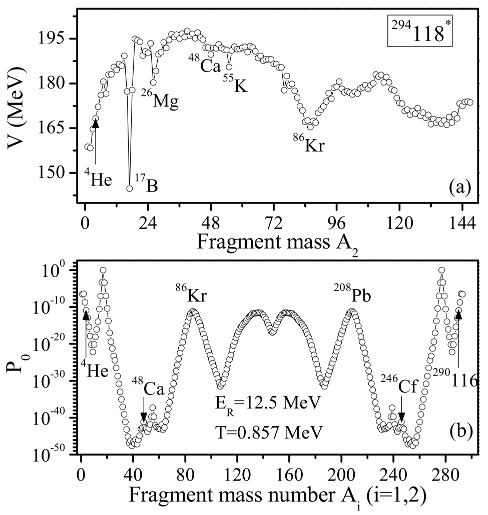

FIG. 2: The fragmentation potential V and preformation probability P_0 for $^{294}118^*$.

for the case of quadrupole deformation β_2 and "optimum" orientations included for all the possible fragments.

The choice of clusters in Fig. 1 is based on the minima in the fragmentation potential and hence for the cases of largest preformation factors P_0, illustrated for Z=118 in Fig. 2. Also, some extra valleys at ^{17}B, ^{26}Mg and ^{55}K fragments are seen in Fig. 2, which get ruled out due to their negligible P values. It is observed from Fig. 1 that ^{4}He is always preformed with the largest probability, though its corresponding P-values are significantly small. The nuclear shell structure effects are also clearly visible in P_0 by its being larger for clusters referring to doubly closed shell ^{208}Pb or its neighboring daughter. Notice that heavy clusters ^{86}Kr, ^{84}Se and ^{80}Ge are preformed with larger P_0 values, compared to ^{48}Ca, respectively, in $^{294}118^*$, $^{290}116^*$ and $^{286}114^*$ parents. This means to depict the stronger closed shell effects of doubly magic ^{208}Pb for ^{86}Kr cluster, compared to that of ^{246}Cf for ^{48}Ca cluster.

Concluding, the calculated half-lives in the present study indicates exciting new possibilities of heavy clusters like ^{86}Kr, ^{84}Se and ^{80}Ge, in addition to α-emission, in the decay of $^{294}118^*$ and its subsequent parents $^{290}116^*$ and $^{286}114^*$.

References

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