Study on structural aspects of the spontaneous fission in superheavy region

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Introduction

The study of α-decay and spontaneous fission (SF) has been of extreme importance to address the dynamical behaviour of nuclear systems, particularly in superheavy mass region. Importantly, the half-lives of such decays are taken as experimental signatures of the formation of superheavy nucleus (SHN) in the heavy ion induced fusion reactions. Both these processes, theoretically, occur due to quantum mechanical tunneling of a preformed α-particle or fission fragment across the potential barrier. Due to large uncertainties in the fission process, such as the mass and charge numbers of the decaying fragments, energy, height and shape of fission barrier, SF has been accounted as more complex process as compared to α-decay. Focusing on the above observations, we have made an attempt to investigate the systematics of SF of ^{282}Cn nucleus appearing as end product [1] in the α-decay chain of ^{294}118 SHN formed via ^{249}Cf+^{48}Ca reaction after 3n emission. Here we intend to analyze the behaviour of potential energy surfaces (PES) along with half-life to explore the possible role of shell closure effects. The calculations have been preformed within the formalism of temperature-dependent preformed cluster model (PCM(T)) [2], for the choice of fragments having quadrupole (β_2) deformations and optimum orientations (θ_i^{opt}).

Methodology

Following the quantum mechanical fragmentation theory (QMFT), PCM(T) is worked out in terms of collective coordinates of mass (η_A) and charge (η_Z) asymmetries, the relative separation R, the multipole deformations $\beta_{\lambda i}$ (λ=2,3,4; i=1,2) and orientations θ_i of decaying heavy and light fragments. Using these coordinates, the mass-fragmentation potential V$_R$(η,T), at a fixed R=R$_a$, is defined as

$$\begin{aligned} V_R(\eta,T) &= -\sum_{i=1}^{2}[B_i(A_i,Z_i,T)] \\ &\quad +V_c(R,Z_i,\beta_{\lambda i},\theta_i,T) \\ &\quad +V_P(R,A_i,\beta_{\lambda i},\theta_i,T). \end{aligned}$$

Here, V_C and V_P are, respectively, the Coulomb and nuclear proximity potentials for deformed and oriented nuclei. The B$_i$(A$_i$,Z$_i$,T) are the binding energies of the two nuclei, given by

$$\begin{aligned} B_i(A_i,Z_i,T) &= \sum_{i=1}^{2}[V_{LDM}(A_i,Z_i,T)] \\ &\quad +\sum_{i=1}^{2}[\delta U_i]exp\left(\frac{-T^2}{T_0^2}\right), \end{aligned}$$

where, the macroscopic term V_{LDM} is temperature-dependent liquid drop energy and δU, the "empirical" shell corrections (for more details see Ref. [2]). The decay constant λ or decay half-life time $T_{1/2}$ in PCM(T) is defined as

$$T_{1/2}=\frac{ln2}{\lambda}, \quad \lambda=\nu_0 P_0 P,$$

where P$_0$ is the preformation probability of decaying fragments and P is the barrier penetrability, referring to η and R-motions, respectively. ν_0 is the barrier assault frequency found to be $\sim 10^{21}s^{-1}$ for SF of ^{282}Cn.

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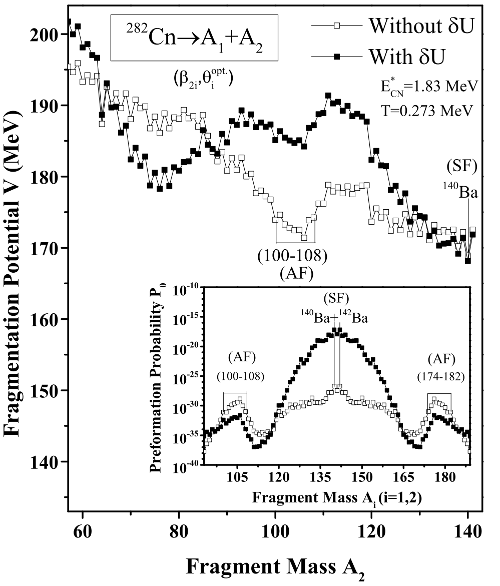

FIG. 1: The calculated potential energy surfaces $V(A_2)$ for the spontaneous decay of ^{282}Cn nucleus plotted to illustrate the significance of shell corrections at E^*_{CN}=1.83 MeV. The inset shows the same but for preformation factor $P_0(A_i)$.

Results and Discussions

First of all, the possible role of shell effects δU in fragmentation potential has been analyzed via Fig. 1, to address the structural aspects in the SF decay of ^{282}Cn nucleus. Both the cases of including δU and not-including δU are considered. Note that we are interested only in the minima of fragmentation potential because the corresponding preformation factor P_0 becomes the largest, compared to its neighbouring fragments. Apparently for both the cases of δU being present or not, we observe strong minima around doubly magic Z_2=50 and N_2=82 (^{140}Ba), and hence corresponding maxima in the preformation profile, labelled as SF. However, the prominence of the same remains intact only when the shell corrections 'δU' are added to the liquid drop part of the binding energy term. In other words, a closer look at the potential energy minima for the case of excluding δU, indicates also some contribution of asymmetric fission fragments, specifically in the mass region of A_2=100-108, denoted as AF. The same results are also depicted in the preformation factor shown in the inset. In other words, our PCM(T) analysis clearly depicts pure symmetric behaviour in preformation profile with inclusion of shell corrections, which changes to triple humped mass distribution for the case of V_{LDM} (δU=0) alone.

TABLE I: The PCM(T) calculated preformation probability P_0, penetrability P and half-life times $T_{1/2}$ presented for α-decay and SF of ^{282}Cn. The experimental $T_{1/2}^{SF}$=$0.82^{+0.30}_{-0.18}$ ms.

Calculated	Parent ^{282}Cn nucleus	
quantities	SF decay	α-emission
P_0	6.54×10^{-18}	1.94×10^{-30}
P	4.58×10^{-2}	4.52×10^{-10}
$T_{1/2}$(s)	8.50×10^{-4}	2.33×10^{17}

Next, to analyze the comparative emergence of the two decay modes, the preformation probability P_0, penetrability P and half-lives $T_{1/2}$ of SF have been compared with those of α-decay for the considered ^{282}Cn parent in Table I at a chosen excitation energy of 1.83 MeV. These observables are calculated at optimized neck-length parameter (ΔR=0.893 fm). The relevant comparison suggests that both P_0 and P comes out to be large for SF, thereby indicating clearly SF channel as the dominant decay mode.

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References

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