Binary and ternary fission analysis of ^{253}Es nucleus using collective clusterization approach

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Introduction

Sometimes one finds three fragments in the outgoing channel instead of usual binary decay, and such kind of process is termed as ternary fission. Generally, the third fragment of ternary fission decay is lighter in comparison to other two main fission fragments, therefore also known as light particle-accompanied fission. The decay of heavier third fragment is also possible for the case of very heavy and superheavy nuclei. The ternary fission was reported for the first time by Alvarez *et al.* in 1947 [1]. Until now, many theoretical and experimental studies have been done to analyze the yield of different fragment channels for the particle-accompanied fission of heavy radioactive nuclei. In the present work, the decay of ^{253}Es is analyzed in view of binary and ternary fission channels. For this nucleus, the possibilities of several third fragments of ternary fission such as ^{4}H, ^{4}He and ^{4}Li are investigated. Apart from this, a relative study of binary fission (decay in two fragments) and ternary fission of ^{253}Es is carried out in terms of fragmentation structure is within the framework of collective clusterization process. The most probable decay fragments in these two fission decay processes are also identified.

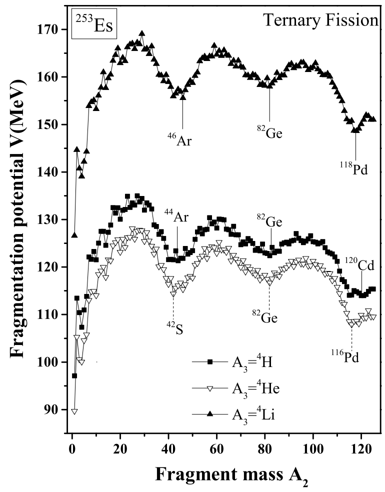

FIG. 1: The ternary fragmentation potential V (MeV) for the ^{253}Es nucleus is plotted for various possibilities of third fragment A_3.

Methodology

In order to analyze the binary and ternary fission of ^{253}Es nucleus, the fragmentation potential is calculated using the quantum mechanical fragmentation theory [2]. This methodology is worked out in terms of collective coordinates of mass (and charge) asymmetry $\eta_A = (A_1 - A_2)/(A_1 + A_2)$ (and $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$) and relative separation R between nuclei/fragments. Here, 1 and 2 described the heavy and light fragments. Third light fragment is fixed (represented by 3), hence the asymmetry coordinates are applicable for fragments 1 and 2 only. For touching configuration, the relative separation between nuclei is taken as $R_{ij} = 1.16(A_i^{1/3} + A_j^{1/3})$; ($i$,$j$=1,2,3). Using these coordinates the collective fragmentation potential for ternary fission is calculated as

$$V = \sum_{i=1}^{3} \sum_{j>1}^{3} (B_i + V_{Cij} + V_{Nij}) \qquad (1)$$

Here, B_i are the binding energies of the three fragments, V_{Cij} is the Coulomb interaction

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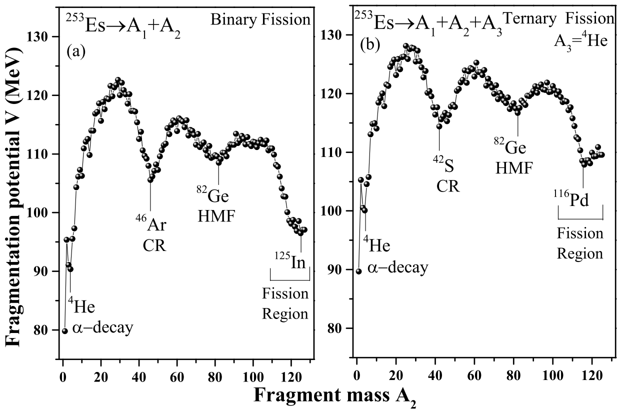

FIG. 2: The calculated fragmentation potential V (MeV) as a function of fragment mass (A_2) for binary and ternary fission of ^{253}Es nucleus.

potential, and V_{Nij}, the short-range Yukawa plus exponential nuclear attractive potential [3]. Eq. (1) can be used to calculate the fragmentation potential for the binary fission, where interaction is taken only between 1 and 2 fragments.

Results and Discussions

Fig. 1 represents the ternary fragmentation potential of ^{253}Es nucleus with third-fragment mass A_3=4. The possibilities of various third fragments of ternary fission such as ^{4}H, ^{4}He and ^{4}Li are investigated in terms of fragmentation potential as shown in Fig. 1. The structure of fragmentation potential is similar for all the choices. However, the magnitude of ternary fragmentation potential corresponding to A_3=^{4}He is lowest. This suggests that ^{4}He-accompanied fission is most preferred for ^{253}Es nucleus. This outcome is in accordance with the observation of Ref. [4].

Further, it is of interest to compare the fragmentation paths of binary and ternary fission of ^{253}Es. For this purpose, the calculated fragmentation potential for both type of fission processes is plotted in Fig. 2(a) and (b). It is evident from figure that the structure of fragmentation potential is somewhat similar with a slight change in the fission region. Apart from this, the magnitude of fragmentation potential is higher for ternary fission as compared to binary fission decay. Besides this, the most probable decay fragments are also identified and marked in the figure. The identified binary and ternary fission decay channels are ^{128}Sn+^{125}In and ^{133}Sb+^{116}Pd+^{4}He, respectively. In both cases, the most favored fission fragments lie in the neighbourhood of proton closed shell Z=50. Apart from this, there are prominent dips at ^{4}He, ^{42}S, ^{46}Ar and ^{82}Ge fragments. This suggests that ^{253}Es nuclear system may also decay through α, cluster radioactivity (CR) and heavy mass fragment (HMF) channels. The relative study of all these decay channels along with binary and ternary fission would be of future interest.

References

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