Alpha accompanied ternary fission of even-even $^{250-256}$Fm isotopes using unified ternary fission model

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Introduction

Once in every few hundred binary fission events, three charged particles are emitted instead of two, and this kind of fission process which produce three fragments are referred to as ternary fission. The ternary fission process was reported for the first time by Alvarez [1] (as reported by Farwell *et al.,*) in 1947. Most of the time, the third particle is found to be an alpha particle but various other light charged particles were also observed in a ternary fission process. The third charged particle formed in the ternary fission process can be emitted in two different configurations; one in equatorial configuration and the other in collinear configuration. In equatorial configuration, the third particle is emitted in a direction perpendicular to the main fission fragments whereas in the case of collinear configuration the third particle is emitted along the direction of the main fission fragments.

Unified ternary fission model (UTFM)

The light charged particle accompanied ternary fission is energetically possible only if Q value of the reaction is positive.

$$Q = M - \sum_{i=1}^{3} m_i > 0 \tag{1}$$

Here M is the mass excess of the parent and m_i is the mass excess of the fragments. The interacting potential barrier V consists of Coulomb potential V_{Cij} and nuclear proximity potential V_{Pij} of Blocki *et al.,* [2] and is given as,

$$V = \sum_{i=1}^{3}\sum_{j>i}^{3}(V_{Cij} + V_{Pij}) \tag{2}$$

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

$$\mathrm{P} = \exp\left\{ -\frac{2}{\hbar}\int_{z_1}^{z_2} \sqrt{2\mu(V-Q)}\,dz \right\} \tag{3}$$

The turning points z_1=0 represent touching configuration and z_2 is determined from the equation $V(z_2)$=Q, where Q is the decay energy. The mass parameter is replaced by reduced mass μ and is given as,

$$\mu = m\frac{A_1A_2A_3}{A_1A_2 + A_2A_3 + A_3A_1} \tag{4}$$

where m is the nucleon mass and A_1, A_2 and A_3 are the mass numbers of the three fragments. The relative yield can be calculated as the ratio between the penetration probability of a given fragmentation over the sum of penetration probabilities of all possible fragmentation as follows,

$$Y(A_i, Z_i) = \frac{P(A_i, Z_i)}{\sum P(A_i, Z_i)} \tag{5}$$

Results and Discussion

The alpha accompanied ternary fission of even-even $^{250-256}$Fm isotopes has been studied using UTFM [3] in equatorial and collinear configuration. The study is based on the concept of cold reaction valley, which was introduced in relation to the structure of minima in the so called driving potential. The driving potential is defined as the difference between the interaction potential V and the decay energy Q of the reaction.

In the alpha accompanied ternary fission of ^{250}Fm isotope, the driving potential for all possible fragment combinations are calculated and plotted as a function of fragment mass number A_1 as shown in figure 1. In the figure 1, the minimum is found for the fragmentations with fragment mass number A_1 = ^{4}He, ^{6}He, ^{10}Be, ^{14}C, ^{20}O, ^{22}O, ^{34}Si, ^{38}S, ^{40}S, ^{44}Ar, ^{46}Ar, ^{48}Ca, ^{50}Ca etc. The fragment combinations found in the cold reaction valley will be the most favourable fragmentations in a ternary fission process. In order to find the most probable fragmentation, the barrier penetrability and the relative yield is calculated using equations (3) and (5). Figure 2 represents the plot of yield obtained for the alpha accompanied ternary fission of ^{250}Fm isotope versus fragment mass numbers A_1 and A_2 in both equatorial and collinear configurations.

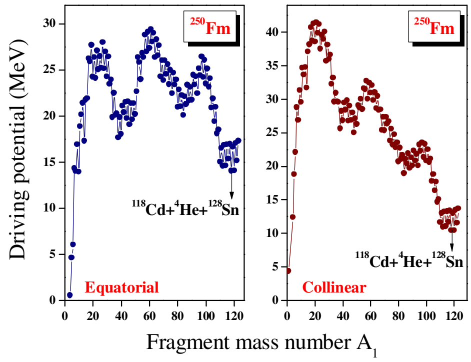

Fig. 1 The driving potential is plotted as a function of fragment mass number A_1 for the alpha accompanied ternary fission of ^{250}Fm isotope.

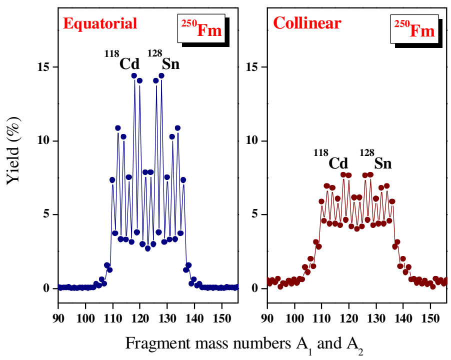

Fig. 2 The relative yield is plotted as a function of fragment mass numbers A_1 and A_2 for the alpha accompanied ternary fission of ^{250}Fm isotope.

From the figure 2, it is clear that the combination ^{118}Cd+^{128}Sn+^{4}He possess the highest yield due to the proton shell closure Z=50 of ^{128}Sn. It is also found that the fragment combinations with the highest relative yield obtained for the equatorial and collinear configuration are the same.

In a similar way, the driving potential, barrier penetrability and the relative yield is calculated for all possible fragmentations using UTFM [3] in the alpha accompanied ternary fission of ^{252}Fm, ^{254}Fm and ^{256}Fm isotopes.

In the alpha accompanied ternary fission of ^{252}Fm isotope, the highest yield is obtained for the fragment combination ^{120}Cd+^{4}He+^{128}Sn in which ^{128}Sn possess proton shell closure Z=50. The next highest yield is obtained for the fragmentation ^{118}Cd+^{4}He+^{130}Sn which includes the presence of near doubly magic nucleus ^{130}Sn (N=80, Z=50).

For the alpha accompanied ternary fission of ^{254}Fm isotope, the highest yield is obtained for the fragment combination ^{120}Cd+^{4}He+^{130}Sn which includes the near doubly magic nucleus ^{130}Sn (N=80, Z=50). The next highest yield is obtained for the fragmentation ^{122}Cd+^{4}He+^{128}Sn.

In the case of alpha accompanied ternary fission of ^{256}Fm isotope, the highest yield is obtained for the fragment combination ^{122}Cd+^{4}He+^{130}Sn, in which ^{130}Sn nucleus is a near doubly magic nucleus. The next highest yield is found for the ternary splitting ^{120}Cd+^{4}He+^{132}Sn in which ^{132}Sn is a doubly magic nucleus (N=82, Z=50).

In the ternary fission of even-even $^{250-256}$Fm isotopes with ^{4}He as light charged particle, the presence of doubly magic nuclei or near doubly magic nuclei plays an important role for the most favourable fragmentations. The highest yield obtained in both the equatorial and collinear configuration is found to be the same. This is mainly because the initial configuration is the same for both the equatorial and collinear configurations. The magnitude of yield obtained for the equatorial configuration is found to be higher than that of collinear configuration which proves equatorial configuration is the most preferable mode in the alpha accompanied ternary fission of even-even $^{250-256}$Fm isotopes.

References

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