Ternary fission of superheavy nucleus Z=126

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Introduction

Theoretical studies on ternary fission as well as heavy particle radioactivity indicate that these exotic decay modes may be a possible decay mode to look for, with respect to the competing α decay mode in the superheavy nuclei. The fission barrier almost vanishes in the superheavy elements [1]. However, the microscopic shell effects strongly enhance the stability of superheavy elements and are reported using theoretical models [2]. Schultheis *et al* [3] calculated the binary and ternary fission barriers in the superheavy nuclei and reported that both are equal within 10%. Further, the relative rates Γ_T/Γ_B are considerably higher in $Z = 126$ isotopes with the consideration of $Z = 114$ and 126 as magic numbers in the shell correction calculations. In this work, we study the ternary fission mass distribution of superheavy nucleus $^{324}126$ with the fixed third fragment A_3= ^{52}Ca and ^{68}Ni within the framework of statistical theory.

The method

Statistical theory is applied to calculate the ternary fragmentation probabilities [4]. The excitation energy of the compound system is shared by the ternary fragments. The excitation energy of each fragmentation is obtained by considering thermal equilibrium attained at scission point [5]. The ternary fission probability of each fragmentation is directly proportional to the product of the level densities of the individual fragments ρ_i, ($i = 1, 2, 3$ for ternary fission) $P(A_j, Z_j) = \rho_1\rho_2\rho_3$. Further, the level density is given as,

$$\rho_i\left(E_i^*\right) = \frac{1}{12}\left(\frac{\pi^2}{a_i}\right)^{1/4} E_i^{*-5/4} \exp\left(2\sqrt{a_i E_i^*}\right). \quad (1)$$

The excitation energy of the fragments is given as,

$$E_i^* = E_i(T) - E_i(T = 0). \quad (2)$$

Within the Fermi gas approximation, the level density parameter a_i can be computed from excitation energy as,

$$a_i = \frac{E_i^*}{T_i^2}. \quad (3)$$

The total energy $E_i(T)$ and the ground state energy $E_i(T = 0)$ of the i^{th} fragment in terms of the single particle energies are calculated by,

$$\begin{aligned} E_i(T) &= \sum_k n_k^Z \epsilon_k^Z + \sum_k n_k^N \epsilon_k^N \\ E_i(T=0) &= \sum_{k=1}^{Z} \epsilon_k^Z + \sum_{k=1}^{N} \epsilon_k^N \end{aligned} \quad (4)$$

where n_k^Z and n_k^N are the occupation probabilities of Z protons and N neutrons of the i^{th} fragment and the summation is for all the single particle energies (s.p.e) considered. The s.p.e of protons ϵ_k^Z and neutrons ϵ_k^N are retrieved from the Reference Input Parameter Library RIPL-3 [4]. Here, only the ground state s.p.e are considered and the temperature effect is included via the occupation number conservation.

For the selection of fragmentations, we consider the charge to mass ratio of the parent nucleus with respect to that of the fission fragments [4]. The relative yield at scission is calculated as the ratio between the probability of a particular ternary fragmentation and the sum of the probabilities of all the possible ternary fragmentations and it is given by,

$$Y(A_j, Z_j) = \frac{P(A_j, Z_j)}{\sum P(A_j, Z_j)}, \quad (5)$$

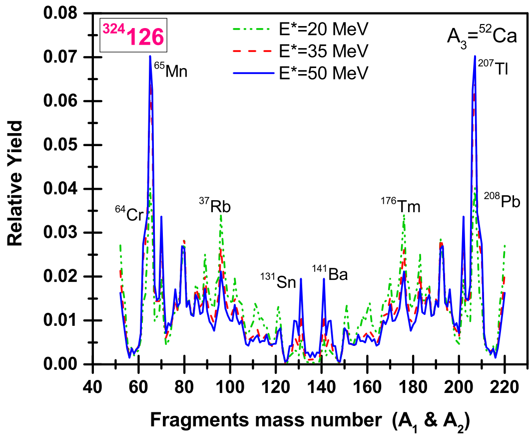

FIG. 1: Ternary fission of ^{324}126 for the fixed A_3=^{52}Ca.

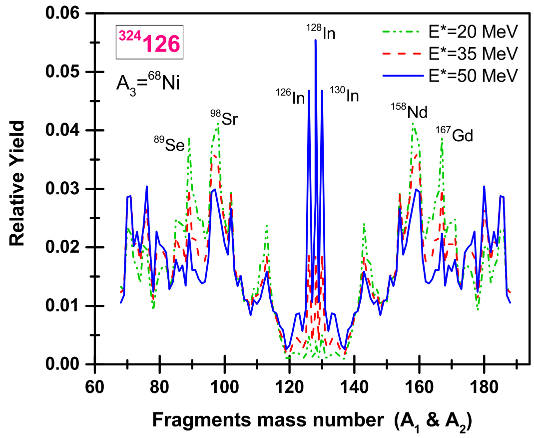

FIG. 2: Ternary fission of ^{324}126 for the fixed A_3=^{68}Ni

with $A_j = A_1 + A_2 + A_3$ and $Z_j = Z_1 + Z_2 + Z_3$. The competing processes such as particle emission, binary fragmentation are not considered in the calculation of ternary yields. The results presented are limited only to relative scission point yields that may lead to prompt disintegration of a parent nucleus into three fragments (democratic breakup).

Results and discussions

In this work, the neutron rich magic number nuclei ^{52}Ca and ^{68}Ni are considered as the third fragments. Further, we considered fixed excitation energies of the parent as E^* =20, 35 and 50 MeV. The fragmentations are obtained using the Z/A ratio with the condition $A_1 \geq A_2 \geq A_3$ which is applied to avoid the repetition of the fragmentations. The fragment excitation energy and the level density are calculated using Eq. (2) and Eq. (1) respectively. The yield values are calculated for the superheavy nucleus ^{324}126 with the fixed A_3 fragment and are plotted in Fig. 1 and 2 as a function of other fragment mass numbers (A_1 and A_2) .

From Fig. (1), for all the excitation energies, the ternary fragmentation $^{207}Tl +^{65} Mn +^{52} Ca$ is found to be the most favourable combination. In addition, at lower E^*= 20MeV, $^{176}Tm +^{96} Rb +^{52} Ca$ is also the favourable combinations. At higher excitation energies E^*= 30 and 50 MeV, the yield values of the fragments with neutron closed shell $N \simeq 126$, 82 increases and for the other fragmentations yield value decreases. Further, for the fixed A_3 =^{68}Ni, $^{158}Nd +^{98} Sr +^{68} Ni$ and $^{167}Gd +^{89} Se +^{68} Ni$ are found as the more probable combinations at E^* = 20 and 35 MeV. At higher E^* = 50 MeV, $^{128,130}In +^{128,126} In +^{68} Ni$ are the most favourable fragmentations with the neutron closed shell around $N \simeq 82$.

In summary, we show that the ternary fragmentation of ^{324}126 is always accompanied with the closed shell at the higher excitation energies.

References

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