Ternary fission of $^{302\text{-}308}120$ even-even isotopes accompanied by ^{14}C

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Introduction

Ternary fission is the breaking of a radioactive nucleus into three fragments. It was formerly proposed by R D Present in 1941 using the liquid drop model [1]. In 1943, experimental observations of light charge particle accompanied ternary fission were reported by Alvarez [2] and Tsien San-Tsiang et al. [3]. In light charge accompanied ternary fission, the third fragment emitted is much lighter compared to the other two, giving rise to two possible configurations known as the equatorial configuration and collinear configuration. In equatorial configuration light charge particle is emitted perpendicular to main fission fragments, whereas in collinear configuration, it is emitted in the direction of main fission fragments.

Unified ternary fission model

Spontaneous cold ternary fission accompanied by light charge particle is energetically possible for the reactions that have positive Q value.

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

Where M is the mass excess of the parent and m_i is the mass excess of the fragments. The interacting potential barrier for a parent nucleus exhibiting cold ternary fission consists of Coulomb potential $V_{c_{ij}}$ and nuclear proximity potential $V_{p_{ij}}$ of Blocki et al. [4], given as;

$$V = \sum_{i}^{3} \sum_{j>i}^{3} (V_{cij} + V_{pij}) \qquad (2)$$

Using one dimensional WKB approximation, barrier penetrability P, probability for which the ternary fragments to cross the three body potential barrier is computed as;

$$P = \exp\left\{ -\frac{2}{\hbar} \int_{a}^{b} \sqrt{2\mu(V-Q)}\, dz \right\} \qquad (3)$$

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Where the turning point a= 0 represents touching configuration and b is determined from the equation V (b) = Q, where Q is the decay energy. a μ is the reduced mass given by the equation;

$$\mu = \frac{m\mu_{12}A_3}{\mu_{12} + A_3} \quad , \mu_{12} = \frac{A_1A_2}{A_1 + A_2} \qquad (4)$$

Here 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,

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

Result and discussion

Investigation has been conducted on the ternary fission of even-even $^{302\text{-}308}120$ with ^{14}C as the light charge particle in equatorial configuration, using the Unified ternary fission model. The most favorable fission channel is determined from their cold valley and relative yield plots. We have computed the driving potential for all possible ternary splitting of parent nucleus at touching configuration for fixing light charge particle A_3, while considering respective mass and charge asymmetries $\eta = \frac{A_1 - A_2}{A_1 + A_2}$ and $\eta_Z = \frac{Z_1 - Z_2}{Z_1 + Z_2}$. Further, the set of charges, which results in the minima in driving potential corresponding to each fixed pair of masses (A_1, A_2) is singled out. Figure 1 represents the cold valley plot for even-even $^{302\text{-}308}120$ isotope with light charge particle ^{14}C. For the parent isotope $^{302}120$, a deep minimum in the cold valley is observed for the $^{4}He+^{284}Cn+^{14}C$ combination. Another minimum is for $^{134}Te+^{154}Sm+^{14}C$ and $^{136}Xe+^{152}Nd+^{14}C$ splitting as they contain respective near doubly magic nuclei ^{134}Te and ^{136}Xe. In the case of the $^{304}120$ isotope, the cold valley shows first two minima for $^{134}Te+^{156}Sm+^{14}C$ and $^{130}Sn+^{160}Gd+^{14}C$ combinations due to the presence of near doubly magic ^{134}Te and ^{130}Sn nuclei, respectively. Subsequent minima in the valley account for the existence of doubly and near doubly magic nuclei such as ^{4}He, ^{132}Te, ^{82}Ge and $^{50,52}Ca$. The minimum in the valley for parent $^{306}120$ is exhibited by the combinations $^{4}He+^{288}Cn+^{14}C$, $^{134}Te+^{158}Sm+^{14}C$ and $^{132}Sn+^{160}Gd+^{14}C$ which has doubly magic nuclei ^{4}He, ^{132}Sn and near doubly magic ^{134}Te. For $^{308}120$ parent isotope, the cold valley shows a deep minimum for the configuration $^{132}Sn+^{162}Gd+^{14}C$ which has doubly magic ^{132}Sn nucleus.

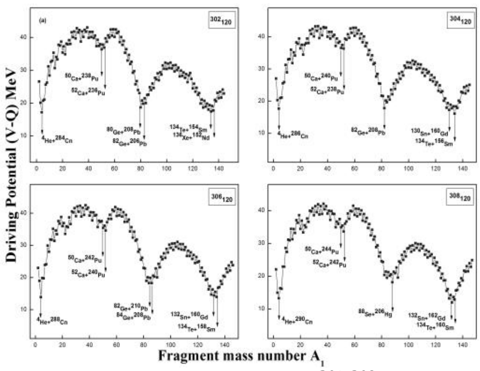

Fig. 1 Driving potential of $^{302\text{-}308}120$ isotopes with ^{14}C plotted as a function of fragment mass number A_1.

The barrier penetrability and relative yield of the above cases are computed. The relative yield plotted against fragment mass number A_1 and A_2 and is shown in figure 2. In the relative yield plot of $^{302}120$ parent isotope, the maximum relative is obtained for the fragmentation $^{134}Te+^{154}Sm+^{14}C$ and $^{136}Xe+^{152}Nd+^{14}C$ as it possesses near double shell closure nuclei ^{134}Te and ^{136}Xe. For $^{304}120$ parent isotope, the same combination $^{134}Te+^{156}Sm+^{14}C$ that gave deep minimum in the cold valley plot, possess highest relative yield due to the presence of near doubly magic ^{134}Te. In the case of $^{306}120$ parent, the highest yield is observed for $^{134}Te+^{158}Sm+^{14}C$ configurations, which have ^{134}Te with neutron shell closure at N=82. The maximum relative yield in the case of $^{308}120$ parent isotope is for $^{132}Sn+^{162}Gd+^{14}C$ which have ^{132}Sn with double shell closure. Fragment configuration that shows minima in the cold valley is found to possess maximum relative yield in the corresponding yield graph. This is due to the existence of magic and near magic nuclei in the fission channel.

Table 1 represents the computed alpha decay half-life using Columb and Proximity Potential Model[5] and Spontaneous fission half-life using the empirical formula of Santhosh et al[6] for the $^{302\text{-}308}120$ isotopes. It is obvious from the table that the computed alpha decay half-life is smaller than the spontaneous fission half-life. For these isotopes the alpha decay is a more probable than spontaneous fission.

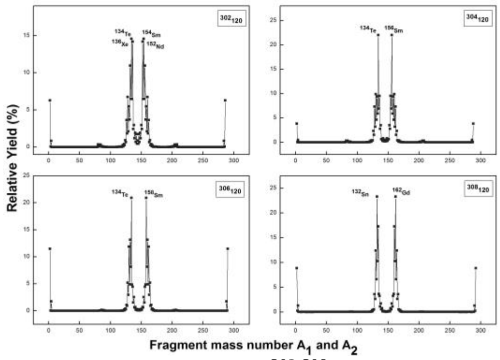

Fig. 2 Relative yield of $^{302\text{-}308}120$ isotopes with ^{14}C plotted as a function of fragment mass number A_1 and A_2.

Parent	Q_α-value (MeV)	$\log_{10}(T_{1/2})$ sec	
		CPPM	SF [6]
$^{302}120$	12.889	-4.578	4.145
$^{304}120$	12.763	-4.324	1.906
$^{306}120$	13.787	-6.538	-0.711
$^{308}120$	12.966	-4.836	-3.690

Table 1: Computed alpha decay and spontaneous fission half-lives of $^{302\text{-}308}120$ isotopes.

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