^{14}C accompanied ternary fission of ^{252}Cf isotope

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Introduction

Ternary fission is a rare process in which three fission fragments are produced from the breakup of a radioactive nucleus. Usually one of the fission fragment is very light compared to the main fission fragments and hence referred to as light charged particle accompanied fission. This kind of fission process was observed for the first time by Alvarez et al. (see Ref. [1]) in 1947, where the light charged particle was found to be ^{4}He in the fission of ^{235}U. In almost all cases, the light charged particle was found to be alpha particle with a probability of once in every 400 binary fission events.

Unified Ternary Fission Model

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

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

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

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

Using one dimensional WKB approximation, the barrier penetrability P, probability for which the ternary fragments to cross the three body potential barrier 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 point $z_1 = 0$ represents touching configuration and z_2 is determined from the equation $V(z_2) = Q$, where Q is the decay energy. The reduced mass is given in equation (4), where m is the nucleon mass and A_1, A_2 and A_3 are the mass numbers of the three fragments.

$$\mu = m \frac{A_1 A_2 A_3}{A_1 A_2 + A_2 A_3 + A_3 A_1} \tag{4}$$

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 Discussions

The ternary fission of ^{252}Cf isotope with ^{14}C as light charged particle for the equatorial configuration is studied using 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 decay energy Q of the reaction. Keeping third fragment A_3 as fixed, the driving potential is calculated for all possible fragment combinations as a function of mass and charge asymmetries respectively given as $\eta = \frac{A_1 - A_2}{A_1 + A_2}$ and $\eta_Z = \frac{Z_1 - Z_2}{Z_1 + Z_2}$, at the touching configuration. For every fixed mass pair (A_1, A_2) a pair of charges is singled out for which driving potential is minimized.

In the ^{14}C accompanied ternary fission of ^{252}Cf isotope, the driving potential is calculated and a graph is plotted as a function of fragment mass number A_1 as shown in figure 1. The minima obtained in the cold valley by keeping the light charged particle as ^{14}C are at ^{4}He, ^{26}Ne, ^{32}Mg, ^{34}Si, ^{40}S, ^{52}Ca, ^{72}Ni, ^{48}Ar etc. The fragment combinations around $^{106}Mo+^{132}Sn+^{14}C$ may possess the highest yield, as it possess doubly magic nuclei ^{132}Sn (N=82, Z=50) and higher Q value, which can be clarified through the calculation of barrier penetrability and hence the relative yield.

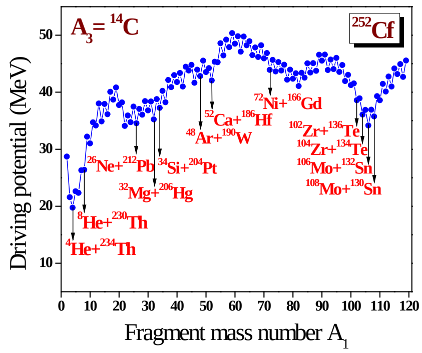

Fig. 1 The driving potential is plotted as a function of mass number A_1 for the ternary fission of ^{252}Cf isotope with ^{14}C as light charged particle.

The barrier penetrability is calculated for all the fragment combinations that occur in the cold reaction valley and hence the relative yield is calculated. In figure 2, the relative yield obtained for the ^{14}C accompanied ternary fission of ^{252}Cf isotope is plotted as a function of mass numbers A_1 and A_2. From the graph it is clear that the highest yield is obtained for the fragment combination ^{106}Mo+^{132}Sn+^{14}C, which possess the presence of doubly magic nuclei ^{132}Sn (N=82, Z=50). The next highest yields are obtained for the fragment combinations ^{108}Mo+^{130}Sn+^{14}C and ^{104}Zr + ^{134}Te + ^{14}C, which is due the presence of near doubly magic nuclei ^{130}Sn (N=80, Z=50) and ^{134}Te (N=82, Z=52) respectively.

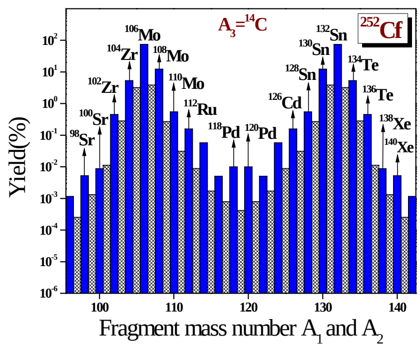

Fig. 2 The relative yield is plotted as a function of mass numbers A_1 and A_2.

The fragment combinations ^{110}Mo+^{128}Sn+^{14}C and ^{102}Zr+^{136}Te+^{14}C possess probable relative yield due to the presence of proton shell closure Z=50 of Sn and near proton shell closure Z=52 of Te nuclei respectively. Our work conclude that, the presence of doubly magic or near doubly magic nuclei plays an important role in the ternary fission process of ^{252}Cf isotope with ^{14}C as light charged particle.

The experimental ternary fission yields of ^{252}Cf isotope with ^{14}C as light charged particle shows that the highest yield is obtained for the fragment splitting ^{106}Mo+^{132}Sn+^{14}C. Using our formalism, the same fragment combination is found to possess the highest relative yield. The calculated relative yields are compared with the experimental data [3] and a histogram is plotted as shown in figure 3, in which the theoretical values are normalized with the experimental data.

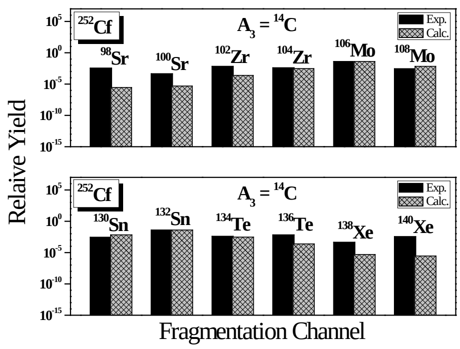

Fig. 3 The relative yields obtained in the ^{14}C accompanied ternary fission of ^{252}Cf isotope are compared with the experimental data.

Acknowledgments

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