Quaternary fission of even-even $^{248-252}$Cf isotopes using the Coulomb and proximity potential

Annu Cyriac, K. P. Santhosh*
School of Pure and Applied Physics, Kannur University, Swami Anandatheertha Campus, Payyanur 670327, Kerala, INDIA
** email: drkpsanthosh@gmail.com*

Introduction

Nuclear fission is generally a radioactive decay process in which two or more fission fragments are formed when the parent nucleus splits. The first pieces of experimental evidence of the existence of quaternary nuclear fission were obtained in studying the spontaneous fission of ^{252}Cf [1] and ^{248}Cm [2] nuclei. The quaternary fission process takes place in two possible modes, the simultaneous or true quaternary and sequential or pseudo quaternary decays. In true quaternary fission, the fission fragments are formed almost simultaneously in the vicinity of nucleus scission point. The pseudo quaternary fission is a sequential decay process and takes place in two stages. The first stage is a ternary fission process with the emission of an unstable light particle, which decays into two light charged particles as the second stage of the fission mechanism.

The Model

The quaternary fission is energetically possible only if Q value of the reaction is positive. ie.

$$Q = M - \sum_{i=1}^{4} m_i > 0 \tag{1}$$

Here M is the mass excess of the parent and m_i is the mass excess of the fragments. The interacting potential barrier, V for a parent nucleus exhibiting quaternary fission consists of Coulomb potential V_{Cij} and nuclear proximity potential V_{Pij} of Blocki et al. [3] and is given as,

$$V = \sum_{i}^{4}\sum_{j>i}^{4}(V_{Cij} + V_{Pij}) \tag{2}$$

Using one-dimensional WKB approximation, the barrier penetrability P, the probability for which the fission fragments to cross the four 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. μ is the reduced mass.

The relative yield can be calculated as the ratio between the penetration probabilities of a given fragmentation over the sum of penetration probabilities of all possible fragmentation as follows,

$$Y(A_i, Z_i) = \frac{P(A_i, Z_i)}{\sum P(A_i, Z_i)} \tag{4}$$

Results and Discussion

The quaternary fission of even-even $^{248-252}$Cf isotope has been 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 the decay energy Q of the reaction. The driving potential ($V-Q$) for a particular parent nuclei is calculated for all possible fission fragments.

Taking ^{252}Cf as the representative parent nucleus, the driving potential for the touching configuration of fragments is calculated for two alpha accompanied quaternary fragmentation and is plotted as a function of fragment mass number A_1 shown in figure 1. Fragments in the cold reaction valley will be the most probable fission fragments. The minima in the cold valley are at ^{4}He, ^{46}Ar, ^{50,52}Ca, ^{82}Ge, ^{86}Se, ^{103,109}Nb, ^{106}Tc, ^{118}Ru etc.

The barrier penetrability is calculated for each charge minimized fragment combinations found in the cold quaternary fission of ^{252}Cf using the formalism described above. Using eq. (4) relative yield is calculated and plotted as a function of fragment mass number A_1 and A_2 as shown in figure 2. The combination $^{112}Mo+^4He+^4He+^{132}Te$ possess the highest yield due to the presence of near doubly magic nucleus ^{132}Te (N = 80, Z = 52). The next higher yield can be observed for the $^{114}Rh+^4He+^4He+^{130}In$ fragment combination due to the presence of near doubly magic nucleus ^{130}In (N = 81, Z = 49).

Similarly cold valley is plotted for quaternary fission of ^{248}Cf and ^{250}Cf isotopes and the most probable fragment combinations are obtained in each case. The barrier penetrability and relative yield are also calculated for each fragment combinations in the cold reaction valley. And hence the most favorable fragment combinations are obtained.

For ^{248}Cf isotope, the combination $^{110}Tc+^4He+^4He+^{130}Sb$ possess the highest yield due to the presence of near doubly magic nucleus ^{130}Sb (N = 79, Z = 51). Other favored channels are $^{108}Nb+^4He+^4He+^{132}I$, $^{106}Tc+^4He+^4He+^{134}Sb$ and $^{112}Rh+^4He+^4He+^{128}In$ as ordered from the most to the less probable ones. As can be noticed, these favored channels include the presence of nearly doubly magic ^{134}Sb (N = 83, Z = 51), ^{128}In (N = 79, Z = 49) and ^{132}I (N = 79, Z = 53).

For ^{250}Cf isotope, the combination $^{110}Rh+^4He+^4He+^{132}In$ possess the highest yield due to the presence of near doubly magic nucleus ^{132}In (N = 83, Z = 49). Other favored channels are $^{112}Nb+^4He+^4He+^{130}I$, $^{108}Zr+^4He+^4He+^{134}Xe$ and $^{114}Tc+^4He+^4He+^{128}Sb$ as ordered from the most to the less probable ones. As can be noticed, these favored channels include the presence of nearly doubly magic ^{134}Xe (N = 80, Z = 54) and ^{128}Sb (Z = 51).

By comparing the relative yields for each isotope, it is found that the maximum yield is obtained for the fragment combinations of ^{252}Cf. Our work also reveals that, the presence of doubly magic or near doubly magic nuclei plays an important role in the quaternary fission of even-even $^{248-252}Cf$ isotopes.

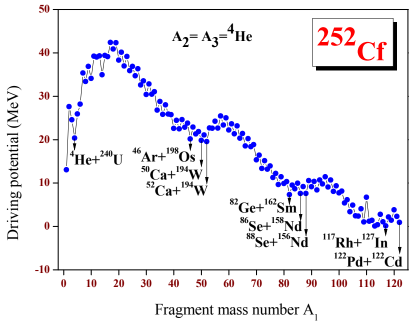

Fig. 1 The driving potential for ^{252}Cf isotope with two ^4He as light charged particle plotted as a function of mass number A_1

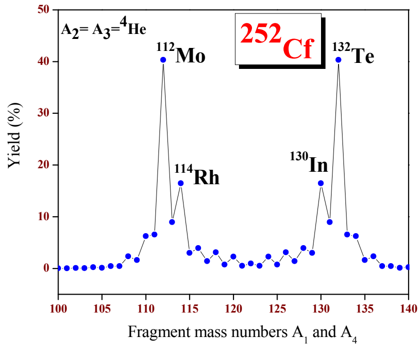

Fig. 2 The relative yields is plotted as a function of mass numbers A_1 and A_2 for ^{252}Cf isotope. The fragment combinations with higher yields are labeled.

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