Isotopic yield in binary fission of even-even $^{244-254}$Cf isotopes

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Introduction

More than seventy five years of research on nuclear fission have clearly shown that, the low energy fission of heavy elements is one of the most complex phenomena of nuclear reactions. Nuclear fission is generally a radioactive decay process in which two or more fission fragments are formed when the parent nucleus splits. Most of the nuclear reactions take place with the binary fission process where only two fission fragments are produced. The first direct observation of cold (neutronless) binary fragmentations in the spontaneous fission of ^{252}Cf was made [1, 2], by using the multiple Ge-detector Compact Ball facility at Oak Ridge National Laboratory, and more recently with the early implementation of Gammasphere [2, 3].

The Model

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

$$Q = M - \sum_{i=1}^{2} m_i > 0 \qquad (1)$$

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 binary fission consists of Coulomb potential and nuclear proximity potential V_P of Blocki et al. [4] and is given as,

$$V = \frac{Z_1 Z_2 e^2}{r} + V_P \qquad (2)$$

Using one-dimensional WKB approximation, the barrier penetrability P, the probability for which the fission fragments to cross the two body potential barrier is given as,

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

The first turning point z_1 and second turning point z_2 are determined from the equation $V(z_1)=V(z_2)=Q$, where Q is the decay energy. The reduced mass is given as,

$$\mu = m \frac{A_1 A_2}{A_1 + A_2} \qquad (4)$$

where m is the nucleon mass and A_1 and A_2 are the mass numbers of the two 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,

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

Results and Discussions

Using the concept of cold reaction valley the binary fission of even-even $^{244-254}$Cf isotopes has been studied. In the study the structure of minima in the driving potential is considered. 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. For every fixed mass pair (A_1, A_2) a pair of charges is singled out for which the driving potential is minimized.

The driving potential for the touching configuration of fragments is calculated for the binary fragmentation of ^{244}Cf as the representative parent nucleus and is plotted as a function of fragment mass number A_1 in figure 1. The combinations in the cold reaction valley will be the most probable binary fission fragments. The minima are found at ^{4}He, ^{14}C, ^{34}Si, ^{36}S, ^{38}S, ^{84}Se, ^{108}Ru, ^{110}Pd, ^{116}Cd, ^{118}Cd etc. The deepest minimum is found for the fragmentation ^{4}He + ^{240}Cm. The minimum found at the fragment combination ^{34}Si+^{210}Po is due to the shell closure at N = 20 of ^{34}Si and shell closure at N=126 of ^{210}Po. Another deep valley occurs for the fragment combination ^{84}Se+^{160}Gd which is due to neutron shell closure at N=50 of ^{84}Se. The minima found for fragment combinations ^{108}Ru+^{136}Xe and ^{118}Cd+^{126}Sn is due to neutron shell closure at N=82 of ^{136}Xe and proton shell closure at Z=50 of ^{126}Sn.

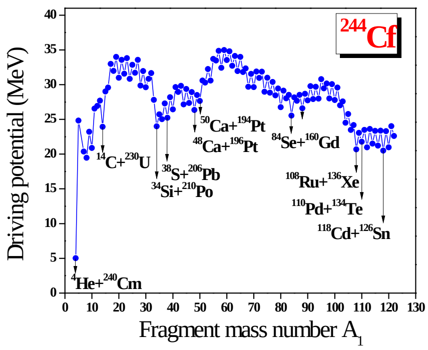

Fig. 1 The driving potential for ^{244}Cf isotope plotted as a function of mass number A_1

The barrier penetrability is calculated for each charge minimized fragment combination found in the cold binary fission of ^{244}Cf using the formalism described above. Using eq. (5) 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 ^{36}S+^{208}Pb possesses the highest yield due to the presence of doubly magic nucleus ^{208}Pb (N = 126, Z = 82).

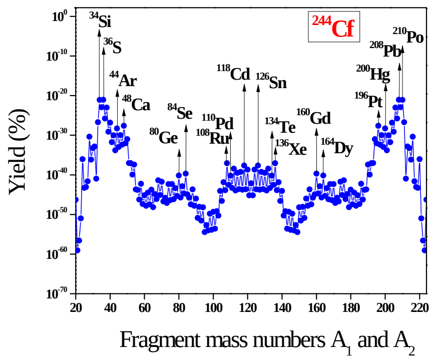

Fig. 2 The relative yields is plotted as a function of mass numbers A_1 and A_2 for ^{244}Cf isotope. The fragment combinations with higher yields are labeled.

Similarly cold valley is plotted for binary fission of ^{246}Cf, ^{248}Cf, ^{250}Cf, ^{252}Cf and ^{254}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 combination in the cold reaction valley.

In the case of the binary fission of ^{246}Cf and ^{248}Cf isotopes, the combinations ^{38}S+^{208}Pb and ^{40}S+^{208}Pb possess the highest yield respectively, which is due to the presence of doubly magic nucleus ^{208}Pb (N = 126, Z = 82). For ^{250}Cf isotope, the fragment combination ^{46}Ar+^{204}Hg possesses the highest yield due to the presence of near doubly magic nucleus ^{204}Hg (N = 124, Z = 80) whereas in the case of ^{252}Cf isotope, the combination ^{46}Ar+^{206}Hg possesses the highest yield due to the presence of near doubly magic nucleus ^{206}Hg (N = 126, Z = 80). For ^{254}Cf isotope, the fragment combination ^{122}Cd+^{132}Sn possesses the highest yield due to the presence of doubly magic nucleus ^{132}Sn (N = 82, Z = 50).

The most favorable fragment combinations for all the six isotopes mentioned above are obtained by calculating their relative yield. Our work reveals that, the presence of doubly magic or near doubly magic nuclei plays an important role in the binary fission of even-even $^{244\text{-}254}$Cf isotopes. It is found that the magnitude of the relative yield increases with increase in mass number (ie. due to the increase in neutron number) of the parent nuclei. Also it is found that highest yield for $^{244,\,246,\,248}$Cf isotopes is for the fragments with isotope of Pb (Z=82) as one fragment, whereas for ^{250}Cf and ^{252}Cf isotopes the highest yield is for the fragments with isotope of Hg (Z=80) as one fragment. In the case of ^{254}Cf the highest yield is for the fragments with Sn (Z=50) as one fragment. It is found that asymmetric splitting is favored for the binary fragmentation of ^{244,246,248,250}Cf and symmetric splitting is favored for the binary fragmentation of ^{254}Cf.

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