Isotopic yield in cold binary fission of even-even $^{230\text{-}244}$U isotopes

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Introduction

One of the main priorities of modern day nuclear structure physics is to completely decipher the idea of nuclear fission which is basically a large amplitude collective phenomenon. Nuclear fission takes place mostly in heavy and superheavy nuclei and involves the evolution of the initial parent system from its ground state to scission. Once the scission configuration is reached, the system splits into two daughter nuclei. Experimental studies of cold fission started in the early 80's by Signarbieux et al., [1] and found that the relative yields of different fragmentation modes are governed by the available phase space of the system at scission, determined by the nuclear structure properties of the fragments. The first investigation of the mass yield in the binary fragmentation for ^{235}U(n_{th}, f),was carried out by Gibson et al., [2].

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 of Blocki et al., [3] and is given as,

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

Here Z_1 and Z_2 are the atomic numbers of the fragments and z represents the distance between the near surfaces of the fragments. The distance between the fragment centres is given by, $r = C_1+C_2+z$, where C_1 and C_2 represents the Süssmann central radii of the fragments.

The proximity potential V_P is taken as,

$$V_p(z) = 4\pi\gamma b\left[\frac{C_1 C_2}{(C_1 + C_2)}\right]\Phi\left(\frac{z}{b}\right) \qquad (3)$$

Φ, represents the universal proximity potential and is calculated using proximity 1977 and proximity 2000. Using one-dimensional WKB approximation, the barrier penetrability P, probability for which the fission fragments to cross the two body potential barrier is given as,

$$\mathrm{P} = \exp\left\{-\frac{2}{\hbar}\int_{z_1}^{z_2}\sqrt{2\mu(V-Q)}\,dz\right\} \qquad (4)$$

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 as,

$$\mu = m\,\frac{A_1 A_2}{A_1 + A_2} \qquad (5)$$

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 probabilities of a given fragmentation over the sum of penetration probabilities of all possible fragmentation as follows,

$$Y(A_i, Z_i) = \frac{P(A_i, Z_i)}{\sum P(A_i, Z_i)} \qquad (6)$$

Results and Discussions

The binary fission of even-even $^{230\text{-}244}$U isotopes 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. 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 fragments in touching configuration for the cold binary fission of ^{230}U is calculated and is plotted as a function of fragment mass number A_1 and is shown in Fig.1. Fragments in the cold reaction valley will be the most probable binary fission fragments. The minima in the cold valley are at ^{4}He, ^{10}Be, ^{14}C, ^{20}O, ^{94}Sr etc. Here the minima are obtained due to the presence of either neutron shell closure or proton shell closure or both.

The barrier penetrability is calculated for each charge minimized fragment combinations found in the cold binary fission of ^{230}U using proximity 1977 and proximity 2000. Relative yield is calculated and plotted as a function of fragment mass number A_1 and A_2 as shown in Fig.2. The combination ^{24}Ne+^{206}Pb possess the highest yield due to the presence of near doubly magic nucleus ^{206}Pb (N = 124, Z = 82).

Similarly cold valley is plotted for binary fission of even-even $^{232\text{-}244}$U 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. For ^{232}U and ^{234}U isotope, the combination ^{24}Ne+^{208}Pb and ^{26}Ne+^{208}Pb respectively possesses the highest yield due to the presence of doubly magic nucleus ^{208}Pb (N = 126, Z = 82). For ^{236}U isotope, the combination ^{30}Mg+^{206}Hg possess the highest yield due to the presence of near doubly magic nucleus ^{206}Hg (N = 126, Z = 80). For ^{238}U isotope, the combination ^{34}Al+^{204}Pt possess the highest yield due to the presence of neutron shell closure at N=126 of ^{204}Pt. For ^{240}U, ^{242}U and ^{244}U isotopes, the combination ^{108}Mo+^{132}Sn, ^{110}Mo+^{132}Sn and ^{112}Mo+^{132}Sn respectively possesses the highest yield due to the presence of doubly magic nucleus ^{132}Sn (N = 82, Z = 50).

It is clear that on using the potentials, proximity 1977 and proximity 2000, we get the highest yield for the same fragment combination for the binary fission of all the chosen uranium isotopes. At the same time, other fragment combinations, as ordered from the most probable to the least probable ones were also same from both the potential calculations. By comparing the relative yields for each isotope it is found that the maximum yield is obtained for the fragment combinations of ^{244}U. Our work also reveals that, the presence of doubly magic or near doubly magic nuclei plays an important role in the binary fission of even-even $^{230\text{-}244}$U isotopes.

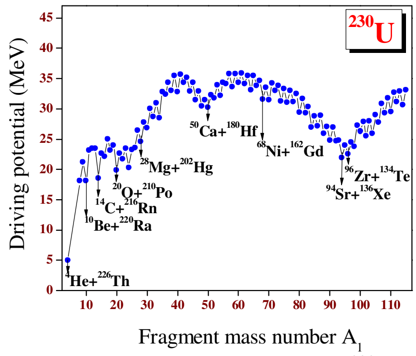

Fig. 1 The driving potential for ^{230}U isotope plotted as a function of mass number A_1

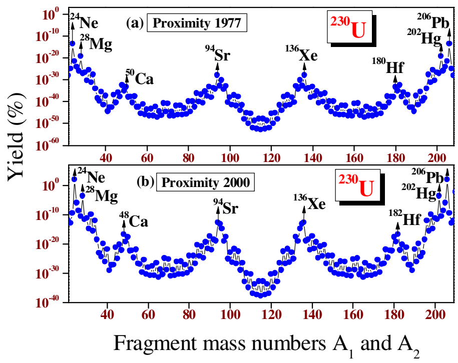

Fig. 2 The relative yields is plotted as a function of mass numbers A_1 and A_2 for ^{230}U isotope.

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