Pre-existence probability mass distribution of binary and ternary fission of ^{236}U

C. Karthika[1], C. Kokila[1], M. T. Senthil Kannan[1], M. Balasubramaniam[1],* and R.K. Gupta[2]
[1]*Department of Physics, Bharathiar University, Coimbatore - 641046, India.*
[2]*Department of Physics, Punjab University, Chandigarh - 160014, India.*

The mass distribution and/or charge distribution of nuclear fission process is an important study. Experimentally as well as theoretically, the mass distribution of binary fission is more or less to a good extent an established topic. However, if the parent nucleus fission into more than two fragments, the mass and/or charge distribution is not well studied. Within the statistical theory, the ternary mass distribution of ^{252}Cf for the fixed third fragment ^{48}Ca was reported[1]. For the first time, the ternary mass distribution with the fixed third fragment using Quantum Mechanical Fragmentation Theory (QMFT) [2] is reported here. In this work, we present the pre-existence probability distribution of binary, α-accompanied and ^{48}Ca accompanied fission of ^{236}U.

Ternary breakup of a given nucleus with mass number A is assumed to form three fragments of mass numbers A_1, A_2 and A_3 such that it obeys mass and charge number conservation. In our convention it is taken as $A_1 \geq A_2 \geq A_3$. If a nucleus undergoes ternary fission it generates a large number of combinations. This is handled by keeping one of the fragment (here third fragment A_3) fixed. The total potential between the three (spherical) fragments within the three cluster model (TCM) is defined as ,

$$V_{tot} = \sum_{i=1}^{3} M_i + \sum_{i=1}^{3}\sum_{j>i}^{3}(V_{Cij} + V_{Nij}) \quad (1)$$

where the first term is the sum total of mass excess of all the three fragments taken from mass table[3]. The Coulomb term is given as,

$$V_{C_{ij}} = \frac{Z_i Z_j e^2}{R_{ij}} \quad (2)$$

with e^2=1.44 MeV fm and R is the relative separation distance between the centers of the fragments A_i and A_j. In this study the calculations are carried out at the touching configuration as : $R_{ij} = c_i + c_j$ where c_i is the Süssmann central radii defined as $c_i = R_i - \frac{b^2}{R_i}$. The radius expression R_i is calculated using,

$$R_i = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3} \quad (3)$$

The proximity potential is taken as the nuclear potential and is defined as,

$$V_{Nij} = 4\pi\bar{R}_{ij}\gamma b\phi(\varepsilon) \quad (4)$$

with $\bar{R}_{ij} = \frac{c_i c_j}{c_i + c_j}$ defining the inverse of the root mean square radius of the Gaussian curvature and $\phi(\varepsilon)$ is the universal function independent of the geometry of the system

$$\phi(\varepsilon) = \begin{cases} -\frac{1}{2}(\varepsilon - 2.54)^2 - 0.0852(\varepsilon - 2.54)^3, \\ \qquad \varepsilon < 1.2511 \\ -3.437exp(-\varepsilon/0.75), \\ \qquad \varepsilon \geq 1.2511 \end{cases} \quad (5)$$

where

$$\varepsilon = \frac{R_{ij} - c_i - c_j}{b} \quad (6)$$

and γ is the nuclear surface energy coefficient given by,

$$\gamma = 0.9517\left[1 - 1.7826\left(\frac{N-Z}{A}\right)^2\right] MeV fm^{-2}, \quad (7)$$

*Electronic address: m.balou@gmail.com

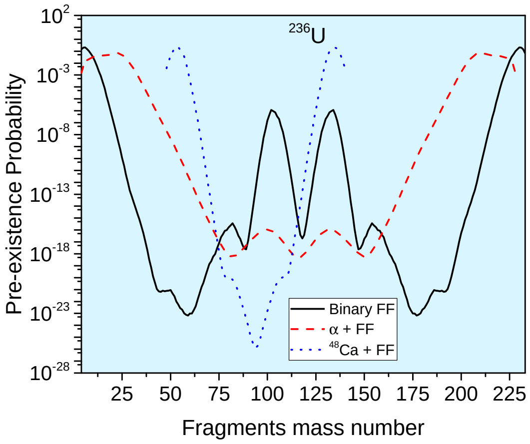

FIG. 1: Pre-existence probability mass distribution for binary, $\alpha-$accompanied and ^{48}Ca accompanied fission of ^{236}U.

is the separation distance between the two surfaces in units of b.

Among the allowed fragment combinations, the favourable ternary fragmentation is identified through the proper charge minimization process. Each of the ternary channel could be identified through binary mass asymmetry parameter η as third fragment A_3 is fixed, it is given by,

$$\eta = \frac{A_1 - A_2}{A_1 + A_2} \tag{8}$$

For η motion, we solve the stationary Schrödinger equation in η at a fixed R,

$$\left\{ -\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} \frac{1}{\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} + V_R(\eta) \right\} \Psi^{\upsilon}(\eta) = E^{\upsilon} \Psi^{\upsilon}(\eta) \tag{9}$$

with υ = 0,1,2,3... corresponding to the ground and excited states. The Eigen solutions of the above equation give the preformation probability,

$$P_0(A_i) = |\Psi(\eta(A_i))|^2 \sqrt{B_{\eta\eta}} \frac{2}{A} \tag{10}$$

where A is the mass number of the compound system. In calculations, the hydrodynamical mass parameter $B_{\eta\eta}$ is replaced by three body reduced mass,

$$\mu = \frac{\mu_{12} A_3}{\mu_{12} + A_3} m \tag{11}$$

where the two body reduced mass is given by,

$$\mu_{12} = \frac{A_1 A_2}{A_1 + A_2} m \tag{12}$$

where m is the nucleon mass.

Results and Discussion

For the use of the potentials between the two/three fragments defined in Eq. (1) and the two/three body reduced masses defined respectively in Eqs. (11) and (12), the equation of motion in mass asymmetry coordinate corresponding to a fixed distance of the centres of the fragments is solved and thereby the preexistence probability is obtained. In Fig. 1, the solid line gives the charge minimized mass distribution values of binary fission of ^{236}U. Dashed and dotted lines presents the mass distribution of α-accompanied and ^{48}Ca accompanied ternary fission of ^{236}U. The mass distributions reveal that, heavy fragment fission group remains more or less within two units of mass whereas the light fragment fission group shifts towards the lower mass for binary and ternary fission. Further, the mass distribution probability of the heavy fragment is lower for the α accompanied fission than binary fission heavy fragment.

The temperature dependence in the potential energies and mass parameters will be studied. Further studies will allow to estimate binary to ternary branching ratio of the fissioning nucleus.

References

[1] M. Balasubramaniam *et al.*, Phys. Rev. C **90**, 054611 (2014).

[2] R. K. Gupta*et al.*, Phys. Rev. Lett. **35**, 353 (1975).

[3] P.Möller *et al.*, At. data and Nucl. data tables, **59**, 185 (1995).