Understanding of scission configuration in heavy-ion induced fission using trajectory calculations

Pawan Singh[1,2], Y. K. Gupta[1,2,*] S. V. Suryanarayana[1], and R. K. Choudhury[1]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400085, India and*
[2]*Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094, India*

Introduction

Neck rupture in fission process is a fascinating example of a delicate interplay of nuclear and Coulomb forces. Particle emission near the scission stage can provide insights about the neck rupture process. It is known since a long time that α particles are emitted perpendicular to the scission axis, which are referred as "equtorial emission" [1–3]. In case of protons, it has been observed very recently that in addition to perpendicular component, a certain fraction is emitted along the scission direction, referred as "polar emission" [4]. Using the final energies of the fission fragments and kinetic energy of the near scission particles (equtorial emission), information about the scission configuration can be obtained by employing inverse trajectory calculations.

Trajectory Calculations

We have performed aforesaid calculations using a three-point charge model [5, 6] for the fission of ^{248}Cf populated through ^{16}O + ^{232}Th reaction. A schematic of the model with different initial parameters is shown in the Fig. 1. The Total Kinetic Energy (TKE) is estimated to be around 182.5±2.5 in the present reaction from Viola's systematics [7]. The final energies of the ternary equatorial protons and α particles are, respectively 5.6±0.4 [4] and 15.6±0.4 MeV [3]. The initial parameters X_0 and Y_0 were set to D/2 and 0 fm, respectively, where D is the distance between the two fragments. The initial angle of the third light charged particle (θ_0) is chosen to be 90° with respect to the scission axis. The trajectories in the mutual Coulomb field of the three point charges were calculated numerically. First, we have investigated how the final energy ($E\alpha_f$) depends on the initial free parameters for the spontaneous fission of ^{252}Cf, and our results were consistent with Boneh's calculations [6]. Next, we performed calculations for the present compound system, ^{248}Cf. As shown in Fig. 2, the final energy of the α-particle ($E\alpha_f$) and the proton (E_{pf}) were calculated as functions of their initial energies, $E\alpha_0$ and E_{p0}, respectively, for different values of the initial parameter Y and an inter fragment distance, D=20 fm. Similar correlations among other scission parameters were investigated.

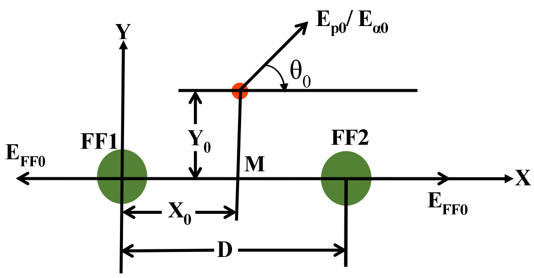

FIG. 1: A schematic diagram of of the three point-charge model, depicting different initial parameters.

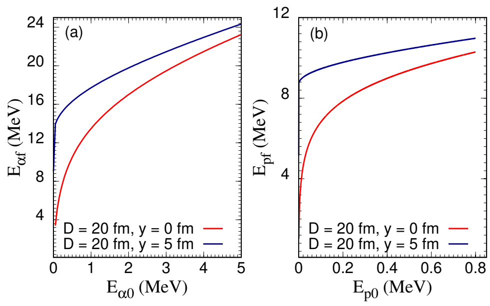

FIG. 2: (a) The final energy of the α-particle ($E\alpha_f$) as a function of its initial energy ($E\alpha_0$) for Y0 = 0 and Y0 = 5. (b) The final energy of the proton (E_{pf}) as a function of its initial energy (E_{p0}) for Y_0=0 fm and Y_0=5 fm.

Results and Discussion

The TKE was calculated in the two dimensional space of initial fragment kinetic energy (E_{FF0}) and distance between both the frag-

*Electronic address: ykgupta@barc.gov.in

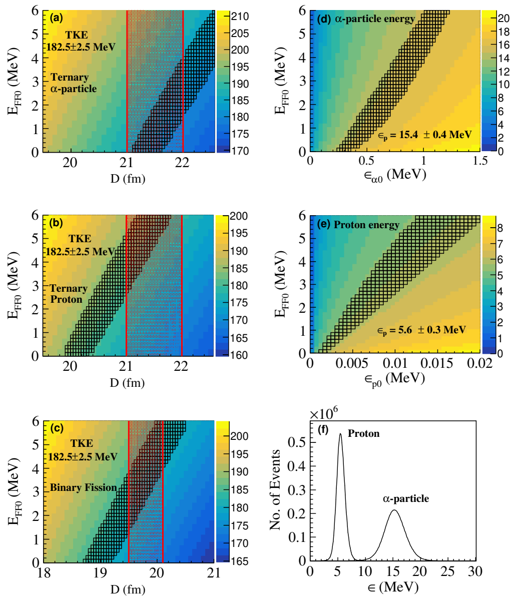

FIG. 3: Results from inverse trajectory calculations: Total Kinetic Energy release in the two dimensional space of initial fragment kinetic energy (E_{FF0}) and distance between both the fragments in ternary α-particle (a), ternary proton (b), and binary fission (c). The dark hatched region represent the experimental value, 182.5±2.5 MeV from Viola's systematics [7]. The vertical red color hatched region represent D=21.5±0.5 fm and 19.8±0.3 fm for ternary and binary fissions, respectively. The final kinetic energy of the third light charged particle (ϵ) in the two dimensional space of E_{FF0} and initial kinetic energy of the third charged particles in panels (d) and (e), where the dark hatched regions represent the experimental peak values. (f) final kinetic energy distribution for ternary α particles and protons using a Monte Carlo technique (see text).

ments (D). These calculations were carried out for binary as well as ternary configurations as shown in the panels (a), (b), and (c) of the Fig. 3. It is seen that in the case of ternary fission (both proton and α-particle) for E_{FF0}=3.9±0.1 MeV, the observed TKE (the sum of all the three charges kinetic energy) is reproduced by D=21.5±0.5 fm (see Figs. 3 (a) and (b)). Whereas in the case of binary fission, for the same E_{FF0}=3.9±0.1 MeV the observed D is significantly lower (19.8±0.3) to reproduce the experimental TKE. It shows that in the case of ternary fission, the scission configuration is significantly stretched. By fixing D=21.9 fm (for ternary α particle) and 21.2 (for ternary protons), the trajectory calculations were further carried out for final kinetic energy of the third light charged particle (ϵ) in the two dimensional space of E_{FF0} and initial kinetic energy of the third charge (E_{p0} & $E_{\alpha 0}$). For a given initial energy of the third charged particle, with increasing the initial fragment kinetic energy, the final energy of the third charged particle decreases. By fixing the E_{FF0}=3.9 MeV as used to reproduce the experimental TKE and keeping D=21.5±0.5 fm, the experimentally observed peak energies of α particles and protons are well reproduced with their initial kinetic energies to be around 1.000 and 0.005 MeV, respectively, as shown in the panels (d) and (e) of the Fig. 3. α-particle emission is energetically more favorable than the proton emission. However, α particles face larger barrier height than the protons, making former to be born with large initial kinetic energy than the latter.

Further, a Monte Carlo technique was used to generate the final kinetic energy distributions of protons and α particles, where aforesaid initial conditions were used with Gaussian distributions. Thus obtained kinetic energy distributions for ternary α particles and protons are shown in the Fig. 3(f). These distributions are having nearly Gaussian shapes with peak values and widths close to experimental values.

Using these inverse trajectory calculations and combining ternary proton and α-particle emissions, the scission stage parameters of a fissioning nucleus have been obtained. It is concluded quantitatively that the scission configuration is significantly stretched in ternary than the binary fission. Detailed results will be presented during the symposium.

References

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