Consistent description of near-scission α-particle emission in low energy and heavy-ion fission via trajectory calculations

Y. K. Gupta,* S. V. Suryanarayana, R. K. Choudhury, D. C. Biswas, L. S. Danu, and B. V. John
Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA

Introduction

The α-particle emission near the scission point, termed as near-scission-emission (NSE), is a very sensitive probe to gain information about the scission configuration [1]. These α particles exhibit characteristic energy and angular distributions corresponding to strong focusing of the particles by the Coulomb field of the nascent fission fragments (FFs). Experimentally, the energy and angular distributions of the FFs and the α-particle, are measured. The scission point parameters (SPPs) are obtained from the data using trajectory calculations [2, 3]. The trejectory calculations have been carried out earlier by many authors, but no unique set of SPPs could be obtained [2, 3]. Systematic determination of the SPPs in a wide energy regime from low energy fission (thermal neutron-induced and spontaneous fission) to heavy-ion fission may shed light on the nuclear viscosity which is a topic of much current research interest.

In our recent work on NSE [1], it is seen from the yield consideration that in heavy-ion fission the near scission α particles are due to statistical emission process in contrast to low energy fission where it is a pure dynamical process [1]. It would be interesting to investigate this changeover in NSE mechanism from the consideration of the the peak value of the energy distribution, ϵ_p of the α particles. In low energy fission, ϵ_p is constant within 15 to 16 MeV as shown in the Fig. 1(a) which is consistent with the dynamical nature. However, in heavy-ion induced fission for different systems it is bunched into two groups as shown in the Fig. 1(b). For

*Electronic address: ykgupta@barc.gov.in

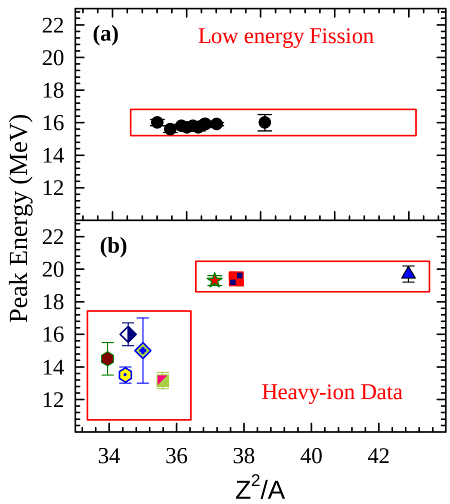

FIG. 1: The peak energy (ϵ_p) of NSE α particles as a function of Z^2/A from low energy fission in (a) and all available data of heavy-ion fission in (b) taken form Ref. [1].

Z^2/A <37, the ϵ_p values are around 15 MeV, whereas for Z^2/A >37 it is around 20 MeV. This change in ϵ_p values in two mass regions may be due to the change in saddle point shapes, as seen from Rotating Liquid Drop Model (RLDM) calculations. The trajectory calculations are expected to play a crucial role in understanding the heavy-ion fission data of ϵ_p.

Trajectory Calculations

The α-particle trajectory calculations are performed in the same line as taken in earlier works [2, 3]. The two FFs and the α-particle are taken as point charges and the trajectories are calculated in the two dimension. With only Coulomb forces between the charges, the Newton's equation of motion are solved numerically. For a description of the scission configuration in low

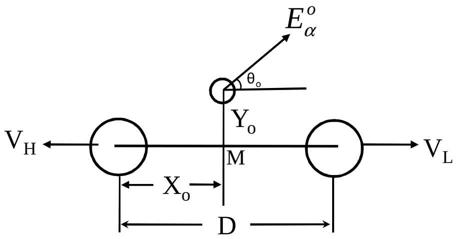

FIG. 2: Schematic diagram of the initial parameters of the calculation.

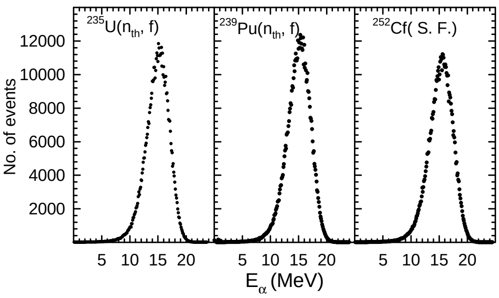

FIG. 3: The final α-particle energy distributions obtained from the Monte-Carlo trajectory calculation typically for three systems.

energy fission, we choose following six initial parameters as depicted in Fig. 2: the inter-fragment distance D, the heavy FF velocity V_H (the corresponding light fragment velocity being fixed by the momentum conservation), the α-particle position with respect to heavy FF (X_o and Y_o), the initial energy (E°_α) and the angle of emission ($\theta_\circ$) with respect to the light FF. In the Fig. 2, the point M correspond to the minimum potential energy in the X-direction.

First, we investigated the dependence of the final energy (E_α) on initial free parameters for spontaneous fission of ^{252}Cf. Obtained results were seen to be consistent with calculation of Boneh et al. [3].

In order to determine the scission point parameters (SPPs) for the low energy fission, Monte-Carlo trajectory calculations are performed for various fissioing nuclei. The binary mass distributions are provided as the input taken from evaluated data library JEFF-3.1.1 [4]. The initial energy distribution of the ternary α-particle is assumed to be of Gaussian shape with certain peak value (ϵ°_p) and the width (σ°_ϵ). The Monte-Carlo calculations with 10^6 No. of events are performed for various set of initial conditions. It is seen that for ϵ°_p =3 MeV, σ°_ϵ= 1 MeV, V_H= 0.4×10^9 cm/s, the peak values of the energy distributions for different low energy fissioning nuclei lie in a narrow range of 15 to 16 MeV which is consistent with the experimental observations. The other initial parameters used in these calculations are as following; D= 26 fm, X_o corresponding to the point M of Fig. 2, Y_o = 0, and $\theta_\circ$=90°. Typical energy distributions for three systems are shown in Fig. 3. From this preliminary calculation it appears that with increasing mass of the fissioning nucleus, the value of V_H remains constant. Therefore, it can be inferred that the prescission kinetic energy of the FFs increases with Z^2/A which is consistent with the two-body viscosity [5].

However, above set of initial parameters reproduces the experimental peak value (ϵ_p) for low energy fission, still it is not a unique set of SPPs. In order to get the unique set of SPPs, the reproduction of the final fragment kinetic energies, in both binary as well as ternary fission, is also needed to be considered. Once we get the SPPs for low energy fission, for which experimental data shows a systematic behavior, it will pave the way for the heavy-ion fission where experimental data for the peak energy are bunched into two groups.

Detailed Monte Carlo trajectory calculations will be presented.

References

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