Measurement of α-particle emission spectra in ^{12}C + ^{209}Bi fission reaction

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Introduction

Nuclear fission is a large-scale rearrangement of nucleons. Heavy-ion induced fusion–fission is central to accessing the superheavy region, yet even after eight decades of its discovery, it continues to show unexpected features. Fission fragment observables such as mass, angle, and kinetic-energy distributions often deviate from compound nucleus expectations, giving rise to the term non-equilibrium (NEQ) fission. Several modes—quasifission, pre-equilibrium fission, and slow quasifission—have been identified, though their origins may share common dynamics. Recent studies revealed that prescission α-particle multiplicity drops sharply across the Businaro–Gallone asymmetry point in ^{232}Th fission induced by various projectiles [1], consistent with earlier angular anisotropy data [2]. While ^{11}B and ^{12}C induced fission follow Halpern–Strutinsky predictions, ^{16}O and ^{19}F exhibit anomalies, and later ^{13}C data suggested the change is gradual rather than sudden. These results have been explained in terms of entrance channel dynamical effects related to the Businaro-Gallone mass asymmetry ($\alpha_{\rm BG}$). It is proposed that in going from highly asymmetric to more symmetric systems, the entrance channel mass flow direction is reversed at a certain point and the compound nucleus formation passes through a di-nuclear configuration. In entrance channels with $\alpha < \alpha_{\rm BG}$, the fissioning nucleus separates prematurely when the fission barrier (B_f) becomes comparable to the temperature (T).

Experimental Details and Data Analysis

Measurements with ^{11}B, ^{12,13}C, ^{16}O, and ^{19}F beams on ^{232}Th confirmed $\alpha_{\rm pre}$ discontinuities in the 45–100 MeV excitation range, coinciding with angular anisotropies. In contrast, pre-scission neutron multiplicity ($\nu_{\rm pre}$) remains smooth with fissility, reflecting its shorter emission timescale and reduced sensitivity to NEQ fission [3].

In the context of above observations, it is quite legitimate to ask whether such a similar $\alpha_{\rm pre}$ discontinuous behaviour will occur in the pre-actinide region. For example, while the composite system formed with ^{232}Th has an isospin parameter of $\sim$0.215, the corresponding value for ^{209}Bi is lower ($\sim$0.19). Moreover, for ^{209}Bi, the entrance-channel asymmetry α lies above $\alpha_{\rm BG}$ for ^{12,13}C and below for ^{16}O and ^{19}F, making it a suitable case for further investigation. We are pursuing heavy-ion induced fission of ^{209}Bi. Earlier we have reported results for α-particle multiplicity spectra at below the BG point in ^{19}F + ^{209}Bi reaction [4]. In pursuit to cover different regions of the BG line, we have now measured α-particle energy spectra for ^{12}C + ^{209}Bi system and presented here.

The α-particle energy spectra were measured in coincidence with fission fragments (FFs) in the ^{12}C + ^{209}Bi reaction at a beam energy of 75 MeV, using the experimental setup shown in Fig. 1. The experiment was carried out with a ^{12}C (75 MeV) beam delivered from the BARC–TIFR 14-MV Pelletron

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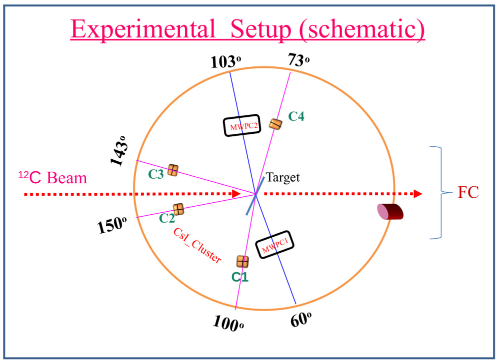

FIG. 1: Schematic view of the experimental setup used for charged-particle multiplicity measurements in heavy-ion induced fission.

accelerator facility in Mumbai. The compound nucleus was populated at an excitation energy of 37.4 MeV. A self-supporting metallic ^{209}Bi foil of thickness ∼1.8 mg/cm^2 served as the target.

Fission fragments were detected using two large-area Multi-Wire Proportional Counters (MWPCs) placed in folding-angle geometry. The MWPCs were positioned at $\theta_f = 60°$ ($\phi = 0°$) and 103° ($\phi = 180°$), with angular openings of 29.2° and 42.0°, respectively. Fission events were cleanly separated from other reaction products by plotting the cathode pulse height of one MWPC against that of the other.

The α-particles emitted in the reaction were detected using seven collimated CsI(Tl)–Si(PIN) detectors, each with an angular opening of ±4°. Energy calibration of the CsI(Tl) detectors was performed periodically using a ^{229}Th α-source, and the light yield beyond 8.4 MeV was extrapolated from in-beam data of earlier measurements [5]. Time correlations between the FFs detected in the two MWPCs were recorded with a time-to-amplitude converter, along with correlations between fission events and coincident α-particles. Around 10^8 fission coincidence events were recorded.

Results and Discussion

The α-particle energy spectra were extracted at several laboratory angles with respect to both the beam axis (θ_α) and the fission fragment ($\theta_{\alpha f1}$), as shown in Fig. 2. After subtraction of random coincidences, clear spectra were obtained for different angular combinations, as shown in Fig. 2. The spectral shapes and yields vary systematically with the angular correlation between the emitted α-particle and the fission fragment, consistent with the charged particle emission during fusion-fission process. The α-particle energy spectra shown in Fig. 2 represent preliminary experimental data. A detailed experimental analysis to get multiplicity spectra followed by moving-source fit will be presented at the symposium.

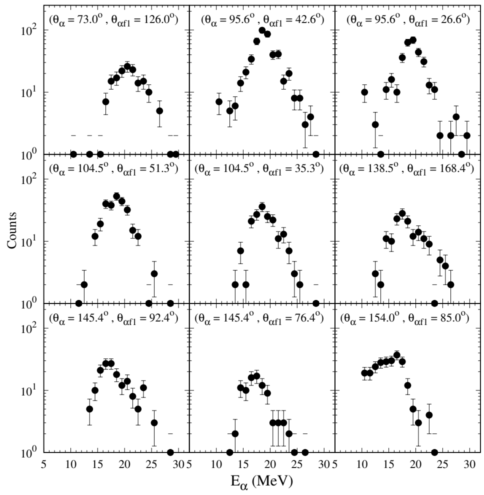

FIG. 2: Preliminary experimental data for α-particle energy spectra measured at different laboratory angles with respect to the beam direction and the fission fragment.

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