Fast Fission in ^{16}O + ^{209}Bi reaction

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Introduction

The synthesis of super heavy elements using heavy-ion-induced reactions is hindered by non-equilibrium processes such as fast fission, quasifission, and pre-equilibrium fission [1]. Precise measurements of mass-energy distributions across a wide range of excitation energies and compound nuclei are essential for understanding the dynamics of these processes. A key challenge in obtaining systematic measurements of pure fission fragment mass distributions at high energies is the increasing complexity with rising excitation energies. This complexity arises from multiple reaction channels [2], including compound nuclear fission, quasi-elastics, deep inelastic reactions, fast fission, and quasi-fission events. Distinguishing fission events from other reaction products becomes progressively more difficult in intermediate or high-energy nuclear reactions.

Here, we report measurements conducted at energies typically 7 - 10 MeV/A for the reaction ^{16}O + ^{209}Bi to understand the dynamics of fusion-fission reactions at relatively high excitation energies.

Experimental details

The experiment was conducted using ^{16}O beam from the K-130 cyclotron at the Variable Energy Cyclotron Centre in Kolkata, India, in the energy ranges of 116-160 MeV. The beams were directed onto ^{209}Bi (400 μg/cm^2) target. To detect fission fragments, two large-area (20 cm×6 cm) position-sensitive multi-wire proportional counters (MWPCs) [3] were positioned at calculated folding angles, chosen based on Viola's systematics, which correspond to symmetric fission fragments. The detectors operated at a low pressure of 3 torr. The time of arrival, impact position, and energy loss of the fission fragments were recorded using a VME-based DAQ system.

Results and discussions

Angular momentum is crucial in nuclear reactions, influencing whether the system undergoes fusion, deep inelastic reaction, or fast fission. As angular momentum increases, different mechanisms dominate. The critical angular momentum (l_{cr}) marks the point where the fusion pocket vanishes; below this, complete fusion forms a compound nucleus, while above it, deep inelastic reactions occur. Beyond the fission threshold (l_{ff}), fast fission becomes dominant, where the system rapidly splits without forming a compound nucleus as there is no fission barrier. At lower energies (e.g., 116 MeV), reactions favor fusion-fission, while at higher energies (160 MeV), higher angular momentum increases the chances of deep inelastic collisions and fast fission. This energy dependence underscores the key role of angular momentum in determining reaction mechanisms.

Our calculation as shown in Fig1 suggests fast fission dominates at 160 MeV, while fusion-fission is more prevalent at 116 MeV. This is because at 160 MeV, major fraction of l values contributing in the reactions are larger than l_{ff}. There is a significant fraction of deep inelastic events (l > l_{cr}) too, hoewever, these are projectile/target like events. Although the low-mass deep inelastic events were not observed due to low detector pres-

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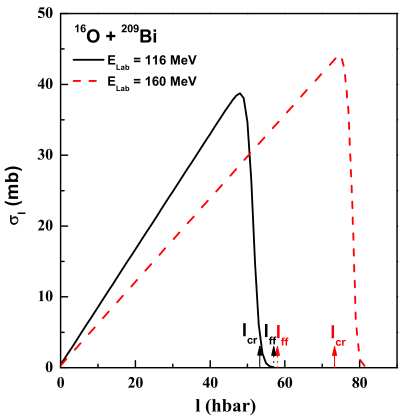

FIG. 1: The figure shows partial capture cross sections versus angular momentum for reaction ^{16}O + ^{209}Bi at 116 MeV and 160 MeV. It indicates the critical angular momentum (l_{cr}) for fusion and the angular momentum (l_{ff}) where fast fission appears at each energy.

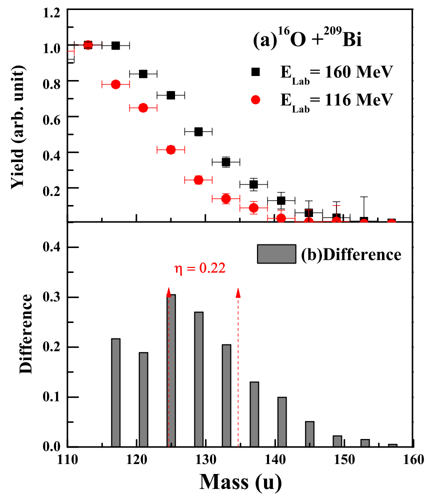

FIG. 2: The fission fragment half-mass distributions for the reaction ^{16}O + ^{209}Bi were measured at the lowest (116 MeV) and highest (160 MeV) energies. (b) The extracted difference between the mass distributions peaks at a mass asymmetry, $\eta = (M_H - M_L)/(M_H + M_L) \sim 0.22$.

sure, fast fission events were detected, with minimal quasi-fission contributions due to the low entrance channel charge for this reaction.

To confirm that the events outside the fusion-fission region in Fig2 (i.e. events with l values beyond l_{ff}) at 160 MeV are due to fast fission, an additional analysis was conducted. Fig2a shows the half-mass distributions for the reaction ^{16}O + ^{209}Bi at 160 MeV and 116 MeV. The mass distributions reveal a distinct asymmetric component, quantified in Fig2b. The mass asymmetry, $\eta = (M_H - M_L)/(M_H + M_L)$, where M_H and M_L are the heavier and lighter fragment masses, is approximately 0.22. This asymmetry is consistent with previous studies [4, 5], confirming it as characteristic of fast fission. Therefore, the observed asymmetry supports the conclusion that the events outside the fusion-fission region at 160 MeV originate from fast fission process.

Conclusion

Our analysis identified fast fission events at higher excitation energies in ^{16}O + ^{209}Bi reaction, characterized by a mass asymmetry of approximately 0.22. Experiments with heavier beam and higher energies may provide critical information about the systematic of fast fission process. Such experiments are planned at the reacently operational K500 Superconducting Cyclotron facility.

References

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