Nuclear reactions with ^{16}O on pre actinide targets at 22.7 MeV/A

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Introduction

The nuclear fission process has been under intense scrutiny for more than eight decades, as it not only has potential to open up avenues for deeper understanding of nuclear forces and the physics behind it, but also because it has offshoots potentially beneficial to mankind. The phenomena has been studied experimentally extensively, and deep insights into the process has been made, specially near the Coulomb barrier, where the fusion fission process competes with the quasi fission process, which has a deep impact on the methodologies selected for the synthesis of Super Heavy Elements (SHE). While, there are some understanding of the nuclear fission process at higher excitation energy and high angular momentum, there is a dearth of experimental data on the evolution of the nuclear fission process at intermediate excitation energies around 20 MeV/A. This is the energy region where beyond mean field processes start manifesting in the nuclear reaction mechanisms [1], and compete with mean field phenomena like fast fission, deep inelastic collisions, etc. A deeper understanding of such mean field phenomena, like fast fission is also need of the hour, as these are the competing reaction mechanisms detrimental to the super heavy production processes, which manifests itself as heavier projectiles are selected for the synthesis experiments. The availability of heavy ion beams of the higher energies at the K 500 Super Conducting Cyclotron (SCC) at VECC, Kolkata opens up an unique opportunity to carry out such extensive experimental endeavours in our country. With that aim in mind, an experimental study was designed to study evolution of the fission like processes with a heavy ion beam of ^{16}O with different pre actinide targets: ^{181}Ta, ^{197}Au and ^{209}Bi. With increase in mass of the target, the fissility of the composite increases. The three reactions so selected also provides an opportunity to test wether the direction of mass flow has any effect on the reaction mechanism, as for ^{16}O + ^{181}Ta, the mass asymmetry between the target projectile combination is greater than the Businaro Gallone mass asymmetry parameter (α_{BG}), implying a mass flow from the projectile to the target. For the other two reactions, ^{16}O + ^{197}Au and ^{16}O + ^{209}Bi, the entrance channel mass asymmetry is less than α_{BG}, implying a mass flow from the target to the projectile.

Experimental details

Heavy ion ^{16}O beam of the highest energy 363 MeV from the K500 SCC at VECC, Kolkata was bombarded on isotopically enriched targets of ^{181}Ta, ^{197}Au and ^{209}Bi. The ^{181}Ta target was of 300 μgm/cm^2 thickness on a backing of 20 μgm/cm^2 of C, while the targets of ^{197}Au and ^{209}Bi were self supporting of thickness 400 μgm/cm^2 and 300 μgm/cm^2 respectively. Two multi wire proportional counters (MWPC) detectors were used for the efficient detection of the heavy fission like fragments. The MWPCs were placed at an angle of 60^0 with respect to the beam axis for the ^{16}O + ^{181}Ta and the ^{16}O + ^{197}Au reactions with an angular coverage of around 40^0 each. For the reaction ^{16}O + ^{209}Bi one MWPC was placed at 60^0 and the other at 80^0 with respect to the beam axis. The angle was so selected to be near the folding angle as predicted by Viola's systematics following full linear

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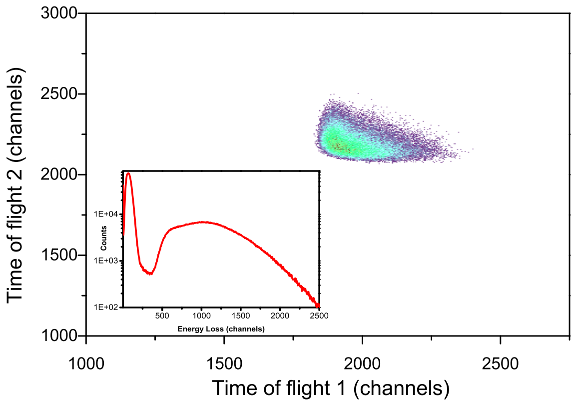

FIG. 1: The timing correlation spectrum from the two MWPC detectors. (Inset) The energy loss spectra from MWPC. The bigger hump on the right hand side shows a clear separation from the quasi elastic particles

momentum transfer. The detectors were operated with 3 torr of isobutane gas for the most efficient detection of fission fragments. The timing correlation spectrum from the anode of the two detectors has been shown in Fig 1. The inset of Fig 1, shows the clean separation between the heavy fission like fragments and the projectile like quasi elastic fragments. The time of arrival of the fission fragments, the position (X and Y) of the point of impact of the fragment on the detector and the energy loss of the fragment in the gas volume were recorded in a VME based data acquisition system on event by event basis.

Result and discussion

The angle subtended by the binary fission fragments in the laboratory frame, (known as the folding angle), is strongly influenced by the reaction mechanisms at play. This is correlated to the recoil energy of the composite undergoing the fragmentation, the recoil energy differing from mechanisms like fusion fission (which follows Viola's systematics) to those from fragmentation from beyond mean filed phenomena like incomplete transfer of linear momentum [2]. The folding angle distribution from the three reactions $^{16}O + ^{181}Ta$, $^{16}O + ^{197}Au$ and $^{16}O + ^{209}Bi$ has been presented in Fig 2, with the Z axis marking the corresponding target. The arrow marks the folding angle corresponding to Viola's systematic following full linear momentum transfer. It can be clearly seen that the peak of the distributions is clearly on the right hand side of the of the peak predicted for Viola's systematic following full linear momentum, indicating events for which the recoil energy (and hence the linear momentum transfer) is lower compared to Viola's systematic. These events have been identified as

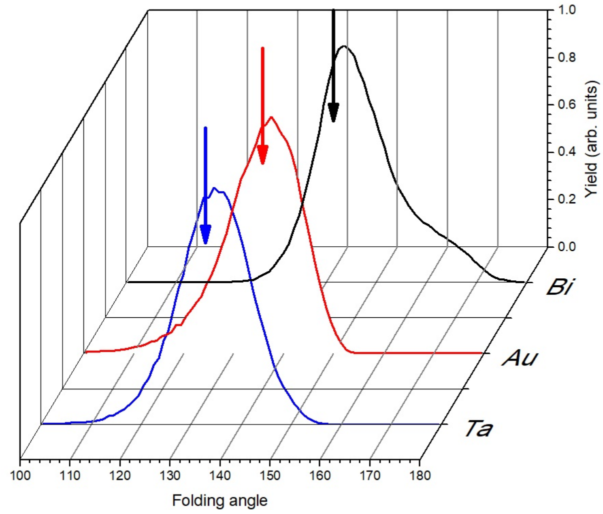

FIG. 2: The folding angle distributions in degrees from the three reactions. The arrow marks the position of the folding angle following Viola's systematics. The z axis shows the target of the reaction

beyond mean field events, with incomplete transfer of linear momentum [3, 4]. It is worth noting that while incomplete transfer of linear momentum events influence all the three reactions at the incident energy of 22.7 MeV/A, the shape of the folding angle distribution itself undergoes a change as the mass of the target increases from ^{181}Ta to ^{209}Bi, with the shape of the folding angle distribution changing from near symmetric Gaussian to a distorted shape with a bulge appearing to the right for ^{209}Bi. These events had been identified by [4] as sequential fission of the target like nucleus following an incomplete transfer of nucleons from the projectile, which can be correlated with a much lower transfer of linear momentum, hence the larger folding angle. This sequential fission following incomplete transfer of nucleons can be correlated with the increase in mass of the target and hence the fissilty of the reaction.

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