Understanding the linear momentum transfer components in the residues produced in $^{19}F+^{159}Tb$ reaction

M. Shariq Asnain[1,*], Mohd Shuaib[1], Ishfaq Majeed[1], Manoj Kumar Sharma[2], Abhishek Yadav[3], Pushpendra P. Singh[4], Devendra P. Singh[5], R. Kumar[6], B. P. Singh[1,#] and R. Prasad[1]

[1]Nuclear Physics Laboratory, Department of Physics, Aligarh Muslim University, Aligarh-202 002, INDIA
[2]Department of Physics, University of Lucnow, Lucknow-226007, INDIA,
[3] Department of Physics, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi-110025, INDIA
[4]Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab- 140 001 , INDIA
[5]Department of Physics, University of Petroleum and Energy Studies, Dehradun-248 007, INDIA
[6]Inter University Accelerator Centre, Aruna Asif Ali Marg, New Delhi-110 067, INDIA
email:*asnainshariq@gmail.com , #bpsinghamu@gmail.com

The study of projectile break-up in heavy ion (HI) reactions has been a topic of interest at energies > 10 MeV/A. However, such reactions have recently been observed at relatively low projectile energies (≈ 4-7 MeV/nucleon). During HI interaction either projectile completely fuses or undergoes break up in the field of target nucleus. As such, the most dominant modes of reactions are complete fusion (CF) and incomplete fusion (ICF) processes. The recent measurements indicate that these processes start competing even at energies just above the Coulomb barrier [1-2]. In case of CF, all nucleonic degrees of freedom are involved due to amalgamation of entire projectile mass carrying input angular momenta $\ell < \ell_{crit}$. This leads to the formation of an equilibrated compound nucleus (CN). However, in case of ICF reactions, the fusion of entire projectile with the target nucleus is hindered for the partial waves with angular momenta $\ell > \ell_{crit}$. In order to provide the sustainable input angular momentum for fusion, the projectile may break up into fragments(s) and one of the fragment(s) fuses with the target nucleus, whereas the remnant continues to move in the forward direction. The break-up or partial fusion of projectile leads to fractional linear momentum transfer from projectile to the target nucleus. Consequently, the composite nucleus formed in case of ICF is likely to have smaller range in a stopping medium as compared to that formed in case of CF reactions. As such, the measurement of forward recoil range distributions (FRRDs) as result of partial linear momentum may be used as one of the most direct and irrefutable methods to distinguish the various CF and ICF components. In FRRD measurements, the residues populated via CF and ICF processes correspond to different characteristic velocity distribution. As such, the experimentally measured yields of different reaction residues as a function of velocity and/or ranges in stopping medium, may be used to obtain the contribution of ICF processes.

With this motivation, an attempt has been made to have a detailed investigation on breakup reactions from the analysis of forward recoil range distribution (FRRD) of heavy residues populated via CF and/or ICF routes. In the present work, the FRRDs of a large number of reaction residues populated in the interaction of $^{19}F+^{159}Tb$ have been measured at two distinctly different beam energies ≈ 83 and 94 MeV.

The experiment for the presently studied system was carried out at the ion beam facility of the Inter University Accelerator Centre (IUAC), New Delhi. The $^{19}F^{8+}$ ion beam was delivered using the 15UD Pelletron accelerator facility. Two separate stacks, each consisting of thin ^{159}Tb target followed by a series of thin Al-catcher foils in the form of a stack were irradiated separately at ≈ 83 and 94 MeV beam energy. The ^{159}Tb target (thickness ≈ 350 μg/cm^2) was deposited by the vacuum evaporation technique on Al-foil (thickness ≈ 2.03 mg/cm^2). The stack of thin Al- catcher foils was placed just after the target so that the recoiling residues populated via CF and/or ICF processes could be trapped at their respective ranges in thin Al-catcher foils. The thickness of target and each Al- catcher foil was measured by α-transmission method. Each irradiation was carried out for ≈ 12 hours in the General Purpose Scattering Chamber (GPSC) [3]. The delay time between stopping of beam irradiation and starting of counting was minimized by taking out the catcher stack using an in-vacuum transfer (ITF) facility. The activities induced in each catcher foil were recorded separately using a pre-calibrated high resolution HPGe γ-spectrometer (100 cc active volume) coupled to a CAMAC based CANDLE [4] software. The identification and confirmation of the residues were done by the characteristic γ-rays and by measuring their half-life. The production cross sections of the reaction products have been determined by using the standard formulation [2].

The FRRDs of various reaction residues populated via CF and/or ICF processes in ^{19}F + ^{159}Tb system have been obtained. In order to obtain the normalized yields, the measured cross section of reaction residues in each Al-catcher foil was normalized by its thickness. The resulting yields were plotted as a function of cumulative catcher thickness in order to obtain the range distribution of identified reaction residues. It was found that the measured FRRDs for *xn* and *pxn* channels have a single Gaussian peak. As a representative case, the measured FRRD for $^{173}W(5n)$ residues has a single peak only at cumulative depth ≈ 567±17 μg/cm^2 indicating that these residues are populated via full linear momentum transfer due to complete fusion process only. Further, the measured FRRDs for α-emitting channels are found to be deconvoluted into more than one Gaussian peak. As a representative case, the FRRD for reaction residues $^{171}Hf(\alpha 3n)$ shown in Fig.1, has two peaks, one at ≈ 567±17 μg/cm^2 which corresponds to full LMT and the other at relatively lower depth (≈381±14 μg/cm^2). The peak at relatively lower thickness (≈ 381 μg/cm^2) may be attributed to the incomplete fusion (fusion of ^{15}N with ^{159}Tb) or due to partial linear momentum transfer from projectile. As such, these residues may have contributions not only from CF but also from ICF processes. Further, the incomplete fusion fraction (F_{ICF}) obtained from RRD data increases as the beam energy (or v_{rel}) is increased suggesting its strong dependence on projectile energy. The critical

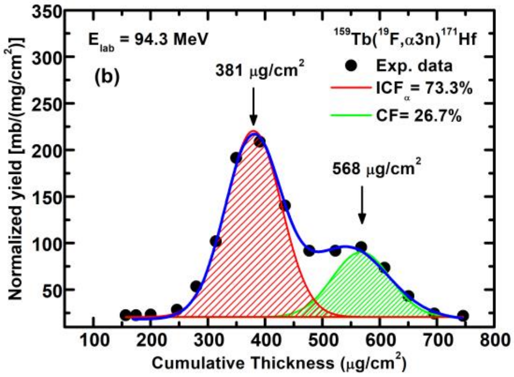

Fig1. The experimentally measured FRRD for $^{171}Hf(\alpha 3n)$ residues at 94.3 MeV

angular momentum ℓ_{crit} for the present system has been calculated and is found to be 79.5$\hbar$. The values of ℓ_{max} at two respective energies in the present work are ≈ 21 and 40$\hbar$ respectively, which are less than the ℓ_{crit} for fusion for this system. As such, observation of ICF even below ℓ_{crit} suggest that there is no clear cut demarcation in ℓ distribution for CF and ICF to occur. In other words, the present results clearly indicate a diffused boundary for ℓ values, contrary to the sharp cut-off model, that may penetrate close to the barrier.

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