Study of pre-compound emission in low-energy heavy-ion interactions: A new experimental method

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The experimental observation of emission of light fast particles (LFP), particularly in the heavy ion reactions at relatively low energies below 6 MeV/nucleon[1] has regenerated interest in pre-compound nucleus (PCN) emission process, since it is expected to occur at high energies ≈10-15 MeV/nucleon. The understanding of the PCN and the compound nucleus (CN) emission in light ion reactions has been well studied during last few decades but in heavy ion reactions it needs to be further explored particularly for those associated with the loss of particles in primary stage in a very short reaction time (10^{-21} s) prior to the establishment of equilibrated CN. The emission of such PCN particles reduces the momentum of the product residues. As such, the measurements of the momentum transfer during the interaction may provide a promising tool for the characterization of the reaction mechanism involved.

The measurement of the momentum transfer may be obtained from the recoil range distributions (RRDs) and spin distributions (SDs) of the reaction residues. Since loss of particles emitted via the PCN process takes away a significant part of angular momentum, the angular momentum associated with the PCN products is relatively lower than that associated with the CN process. Therefore, in PCN reactions, the residues are populated with relatively less high spin states as compared to the spin states of the residues populated via CN process. In order to investigate the role of PCN emission in heavy ion reactions, three self consistent measurements i.e., the RRDs, the SDs and the excitation functions (EFs) have been performed at the IUAC, New Delhi.

This paper reports on the measurements[2] of (i) the RRDs for the reactions ^{169}Tm(^{16}O, 2n)^{183}Ir at incident energy 88 MeV, ^{159}Tb(^{16}O,2n)^{173}Ta, ^{159}Tb(^{16}O,pn)^{173}Hf and ^{159}Tb(^{16}O,3n)^{172}Ta at 90 MeV and for ^{181}Ta(^{16}O, 2n)^{195}Tl reaction at 81, 90 and 96 MeV respectively (ii) the SDs for reactions ^{169}Tm(^{16}O, 2n)^{183}Ir and ^{159}Tb(^{16}O, 2n)^{173}Ta and (iii) the EFs for the reactions ^{169}Tm(^{16}O, 2n)^{183}Ir, ^{159}Tb(^{16}O,2n)^{173}Ta, ^{159}Tb(^{16}O,pn)^{173}Hf, ^{159}Tb(^{16}O,3n)^{172}Ta and ^{181}Ta(^{16}O, 2n)^{195}Tl.

In the RRD experiments, the target followed by a stack of nearly fifteen thin Al catcher foils of varying thickness (≈ 16-45$\mu g/cm^2$ prepared by vacuum evaporation technique) was mounted in the irradiation chamber normal to the beam direction. Depending on the momentum carried away by the product residues, the recoiling residues were trapped at different ranges in the stack of thin Al-foils.

As a representative case, the experimentally measured RRDs for reactions ^{159}Tb(^{16}O,2n)^{173}Ta and ^{159}Tb(^{16}O,3n)^{172}Ta at ≈90 MeV have been shown in Fig 1(a-b).

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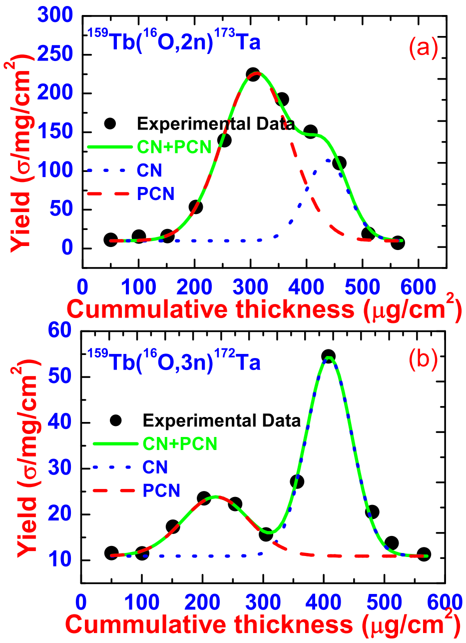

FIG. 1: The experimentally measured RRDs for reactions ^{159}Tb(^{16}O,2n)^{173}Ta and and ^{159}Tb(^{16}O,3n)^{172}Ta at 90 MeV.

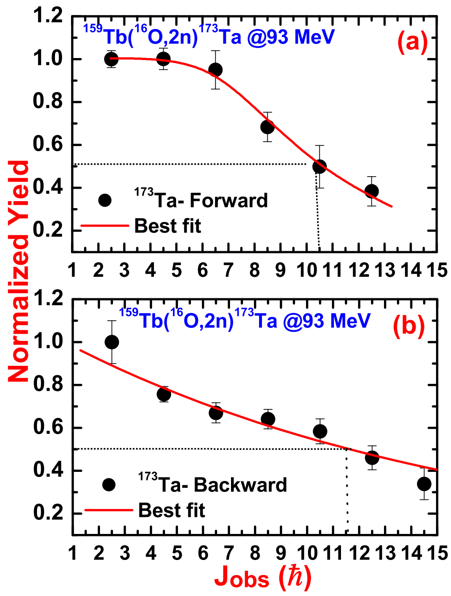

FIG. 2: The experimentally measured forward and backward SDs for reaction ^{159}Tb(^{16}O,2n)^{173}Ta.

The experimental RRDs for these reactions have two peaks, one at a relatively lower value of cumulative catcher thickness (dash cruve in Fig. 1) corresponding to the PCN and the other for the CN at higher thickness (dotted cruve). The theoretical simulations of the experimental RRDs have also been performed.

To further confirm the present findings, anthor experiment based on particle-gamma coincidence technique has also been performed at the IUAC, New Delhi, India for measuring the population of spin states during de-excitation of reaction residues. As a representative case, the SD of the reaction ^{159}Tb(^{16}O,2n)^{173}Ta at ≈93 MeV has been measured using Gamma Detector Array (GDA) alongwith Charged Particle Detector Array (CPDA) and are shown in Fig 2 (a-b). As can be seen from these figures, the entirely different shapes of SDs in forward and backward directions indicate that the two processes (PCN and CN) are quite different in nature. Further in case of CN it is expected that higher spin states in the residues are populated giving rise to linearly increasing population of lower spins due to their feeding from the higher spin states. On the other hand in case of the PCN, residues are left with relatively lower excitation energy and hence with lower spin entry state, therefore, the feeding of lower spin sates is not linear. The above set of two experiments on the RRDs and the SDs is consistent with third experiment on measurements and analysis of the EFs. Further details will be presented.

References

[1] Manoj Kumar Sharma et. al, Phys. Rev C. **91**, 024608 (2015).

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