Validation of alpha-Q-value systematics: response of ^{18}O+^{159}Tb system

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Study of heavy-ion (HI) reactions has received considerable attention in recent years, because the cross-section for such reactions are required to understand the synthesis of super-heavy nuclei and also provides an opportunity to explore the nucleus-nucleus potential. The interest to the in-complete fusion (ICF) reactions in HI-interactions at energies $\approx$ 4-7 MeV/nucleon has aroused during the last decade due to the observation of these reactions at relatively low energies, where complete fusion (CF) is expected to contribute dominantly to the total fusion cross-section [1]. In case of CF reactions, the entire projectile merges with the target nucleus (for $\ell < \ell_{crit}$), with the dominance of the nuclear force field, leading to the formation of excited completely fused composite (CFC) system, with pre-determined charge, mass, excitation energy, etc. However, in case of ICF reactions the projectile may break-up into fragments for $\ell > \ell_{crit}$. One of the fragment may fuse with the target nucleus, forming the excited composite system with relatively less mass, charge and excitation energy as compared to CFC system. The remnant flows in the forward direction with almost beam velocity. Hence, in the ICF processes, the fractional linear momentum transfer takes place. The CF and ICF processes lead to the characteristic velocity distribution of the reaction residues. A variety of theoretical models have been proposed to understand ICF reaction dynamics [2]. The existing models and theories are found to explain the ICF data at energies > 7MeV/A to some extent, but completely fail at relatively lower energies [2, 3]. In addition to this, the dependence of ICF processes on various entrance channel parameters, viz., projectile type and energy, driving angular momentum (ℓ) into the system, binding energy and/or α-Q-value (Q_α), mass asymmetry, deformation of interacting partners, etc., is also required to be explored.

In order to explore above aspects in a consistent way, several experiments have been performed by our group at the Inter-University Accelerator Centre (IUAC), New Delhi. In one of our recent papers, the measurement of EFs for ^{12,13}C+^{159}Tb systems have been done, where significant contribution of ICF reactions have been observed [2, 3]. Here, the probability of ICF for ^{13}C projectile is found to be noticeably smaller than for ^{12}C projectile, which may be understood on the basis of the proposed '*alpha-Q-value systematics*'. Hence, in order to look for the projectile structure effect on ICF reactions in the present experiments the excitation functions of radio-nuclides populated during the interactions of ^{18}O+^{159}Tb at energies $\approx$ 4-7 MeV/A have been measured. The present data will be compared with ^{16}O+^{159}Tb data, to draw some conclusion about alpha-Q-value systematics, as ^{18}O has more negative Q_α-value than ^{16}O. In these experiments the activation technique has been used. The targets of ^{159}Tb of thickness $\approx$ 1.5 - 2.0 mg/cm^2 and *Al*-catchers ($\approx$1.5-2.5 mg/cm^2) were prepared by rolling method. Several stacks of target-catcher assembly (targets followed by *Al*-catcher foils) have been irradiated to cover a wide energy range $\approx$70-

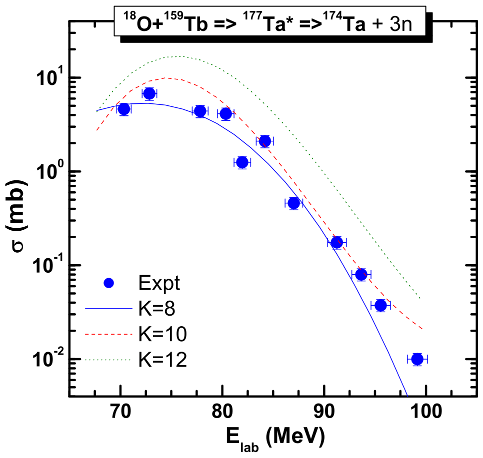

FIG. 1: Experimentally measured excitation function for ^{174}Ta residue produced via $3n$-channel alongwith PACE4 predictions.

100 MeV. Keeping in mind the half-lives of interest, samples were irradiated for ≈8-10 hrs. The activities induced in the samples were recorded by counting each target alongwith the catcher foil, using a pre-calibrated (both for energy and efficiency) HPGe γ-ray spectrometer of 100 c.c. active volume coupled to a CAMAC based CANDLE software. The intensities of the characteristic γ-lines have been used to determine the cross-sections for the residues populated via CF and/or ICF processes.

The excitation functions (EFs) of residues ^{184,183,182,181}Ta (xn; x = 3-6), ^{181}Hf (p5n) and ^{180,179,178}Lu (αxn; x = 3-5) produced in ^{18}O+^{159}Tb interactions have been measured and analyzed within the framework of the statistical model code PACE4 [4]. Detailed definition and listing of input parameters of this code are presented elsewhere [2]. The code PACE4 takes formation and decay of CF events into account according to the Hauser-Feshbach theory of CN decay, therefore, any deviation in the experimental EFs from the PACE4 calculations may be attributed to the onset of ICF. In this code, the level density parameter (a = A/K) is an important input parameter which may be varied to reproduce the experimental EFs. In the present work we tested the experimental data using different values of level density parameters from A/8 to A/12 MeV^{-1}. As a representative case, the experimentally measured and theoretically calculated EFs and the effect of the variation of parameter K for the reaction ^{159}Tb(^{18}O,3n)^{174}Ta identified by characteristic γ-ray of 206.38 keV are shown in Fig.1. As can be seen from this figure the measured EF for ^{174}Ta (3n) channel is in good agreement with the predictions of code PACE4 (K=8), which indicates the production of this channel via CF process only. Similarly, other identified xn and pxn channels are satisfactorily reproduced by the same set of parameters, indicating their population via CF process only. Further, in order to look into the production mechanism of α-emitting channels, the experimentally measured EFs for αxn-channels have also been compared with the PACE4 calculations, where significant enhancements over the calculated values have been found. This enhancement may be attributed as the contribution due to ICF-processes. For a better understanding of ICF process, the ICF fraction has been deduced and found to be energy dependent. Further, details regarding the effect of projectile structure and α-Q-value on the ICF strength function and comparison with ^{16}O+^{159}Tb data will be presented.

References

[1] M. Dasgupta, el al., Phys. Rev. C **70**, 024606 (2004).

[2] Abhishek Yadav, *et al.*, Phys. Rev **C 86**, 064603 (2012).

[3] Abhishek Yadav, *et al.*, Phys. Rev **C 85**, 034614 (2012); ibid **85**, 064617 (2012).

[4] A. Gavron, *et al.*, Phys. Rev. C **21**, 230 (1980).