A Study of Incomplete Fusion in Heavy-ion Reactions at Energies $\simeq$ 4-7 MeV/n

Ishfaq Majeed Bhat[1*]
[1] *Department of Physics, Aligarh Muslim University, Aligarh - 202002, Uttar Pradesh, India*

In the present work, the relative contribution of complete fusion (CF) and incomplete fusion (ICF) reactions in the heavy-ion (HI) collisions has been studied at energies $\approx$ 4 - 7 MeV/nucleon. The fusion-fission in HI reactions has also been studied in this energy range. In the HI collisions, generally, at these energies, the composite system is predominantly formed via CF process, which is considered to be the sole contributor to the total fusion (TF) cross-section [1]. However, in recent years, significant contribution of ICF reactions [2–4] at these energies has also been observed which has created a resurgent interest. In the ICF process, $\ell \geq \ell_{crit}$, the projectile breaks up into fragments. One of the fragments fuses with the target nucleus, leading to the formation of an incompletely fused system, while the other one moves in the forward direction almost with the beam velocity. Several theoretical models have been developed to understand the reactions dynamics of ICF, which are found to be reliable upto some extent only at energies $\geq$ 10.5 MeV/nucleon, but these models could not explain the ICF data at energies $\approx$ 4 - 7 MeV/nucleon. In addition to this, most of the ICF studies have been done using the α-cluster beams like ^{12}C, ^{16}O, and ^{20}Ne. However, the studies using the non-α-cluster beams like ^{13}C, ^{14}N, ^{18}O, and ^{19}F are still limited. Therefore, it is interesting and useful to extend the investigation to study the ICF reactions using the non-α-cluster beams. In view of the above, a comprehensive study of CF and ICF reactions at low energies has been done using the non-$\aleph$-cluster beams ^{14}N and ^{19}F with the heavy target ^{175}Lu. The experiments were performed at the Inter University Accelerator Centre (IUAC), New Delhi using the 15UD pelletron accelerator facility. The ^{14}N and ^{19}F beams with beam current of $\approx$ 3-4 pnA was focused on the isotopically pure self-suporting ^{175}Lu targets. To cover the wide range of energy, stacked foil activation technique followed by off-line γ-ray spectroscopy has been used.

*Electronic address: imbhat@myamu.ac.in

In the excitation function (EF) measurements [4], the reaction residues populated via CF and/or ICF processes in ^{14}N + ^{175}Lu system [4] in the energy range of $\approx$ 4-7 MeV/nucleon have been identified using their characteristic gamma rays and further verified from their half-lives obtained by the corresponding decay-curves. The EF measurements [4] of a large number of evaporation residues (ERs) *viz.* ^{175}Lu(^{14}N,3n)^{186}Pt, ^{175}Lu(^{14}N,4n)$^{185(g+m)}$Pt, ^{175}Lu(^{14}N,5n)^{184}Pt, ^{175}Lu(^{14}N,p3n)^{185}Ir, ^{175}Lu(^{14}N,p4n)^{184}Ir, ^{175}Lu(^{14}N,p5n)^{183}Ir, ^{175}Lu(^{14}N,α2n)^{183}Os, ^{175}Lu(^{14}N,α3n)^{182g}Os, ^{175}Lu(^{14}N,αp3n)^{181}Re, ^{175}Lu(^{14}N,2α4n)^{177}W and ^{175}Lu(^{14}N,2αp2n)^{178m}Ta populated in the interaction of $^{14}N + ^{175}Lu$ system via CF and/or ICF processes have been presented. The experimentally obtained EFs have been analysed within the framework of statistical model code PACE4 [5]. The experimentally measured EFs of xn and pxn channels populated are found to be well reproduced by the statistical model calculations and confirms the production of these channels solely *via* CF process. However, in the case of α-emitting channels, the experimental EFs show significant enhancement with respect to the PACE4 predictions over the entire range of energy. It may be pertinent to mention that, the PACE4 code does not take the ICF into account, therefore, the large enhancement in the experimental EFs of α-emitting channels may be attributed due to the ICF processes. As such, the non-α-cluster beam also gives rise to ICF processes in nuclear interactions Further, the ICF strength function (F_{ICF}), which gives the relative strength of ICF over CF has been deduced from the EFs data and its variation with respect to the entrance channel parameters of incident energy and α-Q value of the projectile has also been studied. Moreover, an attempt has also been made to understand the role of projectile break-up on fusion cross-section [4] within the framework of Universal Fusion Function (UFF). Significant correlation between the suppression factor and break-up threshold energy of the projectiles has been observed suggesting that the observed variation of the probability of the projectile breakup may be a manifestation of the breakup threshold energy effect.

Also, the production cross sections for a good number of fission-like residues populated in ^{19}F + ^{175}Lu system [6] in the similar energy range were measured. The total cross-sections of observed fission fragments at the studied energies are found to be of considerable magnitude. The mass distributions of the fission fragments are observed to be symmetric and single-humped distributions suggesting the formation of the identified fission fragments from the fully equilibrated compound nucleus. The production of the fission fragments from breaking up (fission) of a fully equilibrated system is further supported with the proximity of the most probable mass and half of the compound nucleus mass at both the studied energies. The mass distributions are found to get broader with the incident energy indicating the population of broader mass range fission fragments for higher excitation energies and vice versa.

Furthermore, the calculation of independent cross-section for a nuclide being populated via precursor feeding (which is quite common in HI fusion and fission processes) as well as the reaction process is confronted [7] in a general way eliminating the assumptions and difficulties reported earlier. A general mathematical formulation for deducing the independent production cross-section of the daughter nuclei from the cumulative cross-section is obtained [7]. The mathematical formulation has been tested and verified with the real experimental data. The generalized mathematical formulation has been found to yield justified values of cross-sections for all the cases in contrast to the traditional formulation which is valid only for a narrow range of possibilities and found to fail miserably beyond the range. The results obtained with the new procedure will be useful for testing the predictions of the theoretical models. Further details will be presented.

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