Partial Waves: An approach to understand Incomplete Fusion

R. Kumar[1],* Vijay R. Sharma[2], and R.K. Bhowmik[3]

[1] *Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110 067, INDIA*

[2] *Physics Department, Aligarh Muslim University, Aligarh - 202 002, INDIA and*

[3] *Department of Physics, Guru Ghasidas University, Bilaspur - 495 009, INDIA*

The dynamics of incomplete fusion (ICF) has been extensively investigated in heavy ion (HI) induced reactions at energies near and/or above the coulomb barrier, where ICF is found to compete with complete fusion (CF) at energies 4-7 MeV/A. However, the complex mechanism of incomplete mass transfer is still not well understood and, thus, continues to be an active area of investigations. Recently, it was observed in several studies that the projectile, before its break-up, losses a significant amount of energy in the interaction with the target nucleus and later, there may be complete and/or partial momentum transfer may takes place [1–3]. As HI reactions are associated with large angular momentum, therefore, a proper understanding of entrance channel partial waves is important in the study of ICF. It may be relevant to mention here that, the compound nucleus formation is hindered due to the rapid rotation of the composite system which cannot exist as such and hence only a part of the projectile can fuse with the target. Further, only a few lower partial waves contribute to CF at higher angular momenta whereas, higher order partial waves contribute to ICF thereby reducing the CF cross section. In this regard, Wilczynski [4] showed the limitation in cross-section by hard grazing angular momenta (ℓ_{hg}) and interpreted their results in terms of generalized concept of critical angular momenta (ℓ_{crit}). Though, these results were obtained and valid at beam energies more than 10 MeV/A, which envisages the localization of the different ICF channels in the angular momentum space above the critical angular momentum for CF. The data at lower beam energy could not be explained through Wilczynski model owing to the fact that the maximum angular momentum values ℓ_{max} are close to the critical angular momentum ℓ_{crit}, thereby, precluding any window for ICF below ℓ_{crit}. Few, previous studies showed the involvement of angular momentum much lower than ℓ_{crit}, [5, 6], therefore, ICF associated at beam energies $\approx$ 4-7 MeV/A is not still clearly understood.

In order to emphazise the above aspects, an attempt has been made to carry forward Wilczynski model at beam energies i.e. $\approx$ 4-7 MeV/A by assuming a Fermi-like function (f_l) to describe the competition between CF and ICF processes. The data of the experiments carried out for ^{12}C,^{14}N,^{16}O+^{169}Tm and ^{16}O+^{159}Tb,^{103}Rh systems at the Inter-University Accelerator Center (IUAC), New Delhi, using recoil-catcher technique followed by offline γ-spectroscopy have been used to obtain the fusion cross-sections. The details of the experiments are given elsewhere [1, 2, 5].

The experimental total fusion cross-section 'σ_{TF}' for the ^{12}C,^{14}N,^{16}O+^{169}Tm and ^{16}O+^{159}Tb,^{103}Rh systems, which may be attributed to the both complete and/or incomplete fusion have been deduced at respective projectile energies. However, contribution of the ICF has been deduced by subtracting the CF cross-section obtained by code PACE from experimentally measured cross-section at respective projectile energies, as suggested by Gomes et al [7]. In order to describe the relation confirmation of CF and ICF, femi-like function (f_l) is incorporated with the prescription given by Wilczynski et al [4]. It may be pointed out that underestimation of the ICF cross-section by using Wilczynski

*Electronic address: rakuiuac@gmail.com

prescription was due to the assumption that a major contribution to the ICF reaction comes from the collision trajectories with the angular momentum greater than crtical value of the angular momentum (ℓ_{crit}). The critical value of the angular momentum for different projectile-target combinations have been calculated using standard formulation, and are tabulated in Table-1. However, the

TABLE I: Empirical parameters for the presently studied systems.

Systems	Critical angular momenta ℓ_{crit}	Ref.
^{16}O+^{169}Tm	61	[1]
^{14}N+^{169}Tm	51	[5]
^{12}C+^{169}Tm	46	[2]
^{16}O+^{159}Tb	55	[1]
^{16}O+^{103}Rh	43	[6]

partial cross-section have been calculated using code PACE which is based on the Bass fusion cross-section algorithm. The transmision probability associated with the partial waves can be calculated using the one dimensional barrier penetration model. To the best agreement experimental excitation functions (EFs) have been obtained for the values of a=A/8.0 MeV^{-1} and the value of the diffuseness parameter has been set to 0.2 for the calculations. In order to account for CF cross-section 'σ_{CF}' and ICF cross-section 'σ_{ICF}', the Bass fusion cross-section formulasism is normalized with the presently assumed fermi-like function (f_l). For CF cross-section; $\sigma_{CF} = \sigma_l . f_l$ and for ICF cross-section; $\sigma_{ICF} = \sigma_{TF}$.(1-$f_l$). Based on the above presently assumed prescription, a Multi-step pArtial Reaction Cross-section (*MARC*) code has been developed, which is able to reproduce relative yields of CF and ICF. The total partial cross-section '$\sum\sigma_{ICF}^{MARC}$' values for the systems ^{12}C,^{14}N,^{16}O+^{169}Tm and ^{16}O+^{159}Tb,^{103}Rh using code MARC at different scaling parameter 'Δ' are compared with experimentally measured and systamatically deduced values of $\sum\sigma_{ICF}^{Exp}$ as a function of normalized angular momentum $(\ell_{max}/\ell_{crit})^2$. As a representative case for

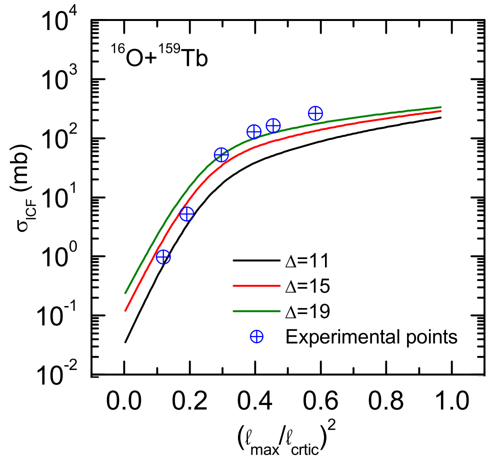

FIG. 1: Total partial cross-section $\sum\sigma_{ICF}^{MARC}$ using MARC code at different scaling parameter 'Δ' (read in text) as a function of normalized angular momentum.

the ^{16}O+^{169}Tm have ben plotted in Fig.1. As can be seen from this figure, the values of $\sum\sigma_{ICF}^{Exp}$ are in high degree of agreement with the MARC code output for Δ= 11. The result presented in Fig.1, suggest a significant ICF contribution below ℓ_{crit} values. Further, details and justification of the variation of the scaling parameter Δ will be presented.

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