Probing the systematics for low energy incomplete fusion with Universal Fusion Function model

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In the recent years, a renewed interest has emerged, in the study of heavy ion (HI) reactions to investigate the effects of breakup and fusion processes at energies around the Coulomb barrier [1, 2]. In HI reactions the complete fusion (CF) takes place when all the nucleons of the projectile & target nuclei lose their identity to form a single complex system followed by equilibration of the compound system. On the other hand, incomplete fusion (ICF) occurs, when only a part of projectile fuses with the target nucleus and remaining part escapes with nearly incident beam velocity. In order to explore the dynamics of HI reactions, a number of studies has been done within the framework of entrance channel parameters with weakly as well as strongly bound projectiles. Strongly bound projectiles have also been shown to breakup with a significant yield at energies around the Coulomb barrier i.e. ≈ 4-7 MeV/A [3-5]. In this sequence, high intensity beams like ^{6,7}Li, ^{9}Be, ^{16}O, ^{12}C, etc., have been used as a reference for developing and testing of the incomplete fusion model proposed recently [6]. Some of the most widely employed models to explain ICF data are the (i) breakup fusion model, (ii) sum-rule model, (iii) exciton model, (iv) hot-spot, (v) promptly emitted particles model, and (vi) overlap model (see reference [1-2] for more details). The aforementioned models have been used to fit the experimental data obtained at energies well above the Coulomb barrier (i.e., Elab ≥ 10.5 MeV/nucleon) but have shown certain failings in their ability to explain ICF data at relatively low bombarding energies (i.e., ≈3–7MeV/nucleon).

Recently *Canto et.al.* [7], proposed a universal fusion function model which can disentangle the couplings effects associated with the reaction process via studying the dynamic and static effects, and can be used to study the breakup fusion as well. In the present work, an attempt has been made to study the target dependence on experimentally modified fusion function as suggested by *Canto et al.* [7]. The experimental data from the experiment performed at IUAC, New Delhi for the ^{12}C projectile on ^{159}Tb target [2] alongwith ^{12}C+^{46}Ti, ^{12}C+^{48}Ti, ^{12}C+^{50}Ti [8] from the available literature has been renormalized within the framework of recently proposed Universal Fusion Function (UFF) approach [7]. In this model a complete fusion reaction function; $F_{expt} = 2E\sigma_{CF}/(\hbar\omega R_B^2)$ has been plotted against the dimensionless quantity $x = (E - V_B)/\hbar\omega$, where ħω is the barrier curvature. However, to eliminate the coupling effects the complete fusion reaction function is renormalized to obtain the reaction fusion function (RFF) as $F_{expt} \rightarrow \boldsymbol{F}_{expt} = F_{expt}(\sigma_F^{W}/\sigma_F^{CC})$, where σ_F^{W} is the fusion cross section calculated by the Wong approximation of 1DBPM [9] and σ_F^{CC} is the cross section obtained with coupled-channel calculations code CCFULL [10]. The values of the barrier curvature parameters used alongwith barrier radius 'R_B', and potential barrier 'V_B' for the systems studied in the present work are given in Table 1. The renormalized $F_{expt} \rightarrow \boldsymbol{F}_{expt}$ is compared with a UFF i.e $F_0(x) = \ln[1 + \exp(2\pi x)]$. It may be pertinent to mention that the analytic expression to calculate the fusion cross section was first given by Wong's [10] as,

$$\sigma_F^W(x) = R_B^2 \frac{\hbar\omega}{2E} \ln\left[1 + exp\left(\frac{2\pi(E - V_B)}{\hbar\omega}\right)\right]$$

TABLE 1: Empirical parameters for the presently studied systems.

Systems	R_B (fm)	V_B (MeV)	ħω (MeV)
$^{12}C+^{46}Ti$	8.15	19.65	4.11
$^{12}C+^{48}Ti$	8.20	19.49	4.07
$^{12}C+^{50}Ti$	8.25	19.33	4.03
$^{12}C+^{159}Tb$	10.80	48.78	4.84

where the symbols used have their usual meaning.

The renormalized $F_{expt} \rightarrow \boldsymbol{F}_{expt}$ is plotted on the log and linear scales as a function of dimensionless quantity $x = (E - V_B)/\hbar\omega$ in fig. 1 (a & b) respectively.

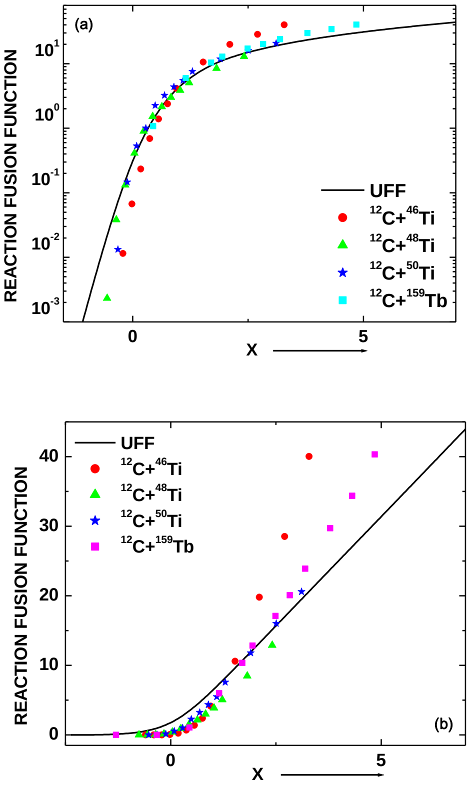

Fig: 1 Comparison of modified reaction fusion function (RFF) with UFF for several systems in (a) logarithmic and (b) linear scales.

A comparison of RFF with UFF indicates the deviation, relatively larger as compared to UFF line. This enhancement of the measured RFF may be attributed due to the strong coupling of break-up channels on the TF processes. More data covering relatively high energy portion for $^{12}C+^{48}Ti$ and $^{12}C+^{50}Ti$ systems will give useful information regarding breakup effects at these energies. Further, the comparison of different targets with same projectile may be used to explain any deviation with respect to UFF and will be presented.

The authors thanks to the Chairman, Department of Physics, Aligarh Muslim University, Aligarh for providing necessary facilities. RP, BPS, VRS, MS thanks to DST for providing financial support vide project no: SR/S2/HEP-30/2012.

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