Projectile break-up effects on fusion in $^{12}C,^{16}O+^{159}Tb$

Vijay R. Sharma[1],* Abhishek Yadav[1], Pushpendra P. Singh[2], Devendra P. Singh[1], R. Kumar[3], Manoj K. Sharma[4], B. P. Singh[1], and R. Prasad[1]
[1]*Department of Physics, Aligarh Muslim University, Aligarh - 202 002, INDIA*
[2]*GSI Helmholtz, Centre for Heavy Ion Research GmbH, Darmstadt - 64291, GERMANY*
[3]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA and*
[4]*Physics Department, S. V. College, Aligarh - 202001, INDIA*

Recently a renewed interest has emerged, in heavy-ion (HI) reactions, for the study of break-up and fusion processes at energies near the Coulomb barrier, involving both the stable and unstable beams. This has primarily been motivated by the availabilty of radio-active ion beams. However, studies using radioactive ion beams are limited due to low beam intensities. Fusion studies using stable beams have indicated that at energies near the barrier, the fusion is strongly influenced by the stucture of the interacting nuclei, and also by the presence of transfer processes. In HI reactions, the complete fusion (CF) is associated with the capture of all the projectile-constituents by the target nucleus. On the other hand, incomplete fusion (ICF) occurs when a part of the projectile is captured by the target nucleus and the remaining part escapes with nearly beam velocity. Thus, total fusion probability 'σ_{TF}' may be taken as the sum of these two i.e., $\sigma_{CF}+\sigma_{ICF}$. Several models have been proposed to explain the features of these processes. Recently, high intensity beams of ^{6,7}Li and ^{10,11}B having large breakup probabilities, have been used [1] as references for developing and testing the Break-up Fusion (BUF) Model [2]. However, the break up of strongly bound (^{12}C and ^{16}O) projectiles giving rise to increase in the total fusion cross-section 'σ_{TF}', when bombarded on medium mass range targets (^{169}Tm, ^{159}Tb) are also reported [3, 4]. In this work, a systematic study of the effect of projectile breakup on ^{159}Tb target from weakly bound nuclei to strongly bound nuclei has been carried out by using recently proposed reduction methodology [5]. One of the important points of investigation is whether the break-up of projectile is responsible for increase in the cross-section.

In the present work the data of the experiments carried out, for $^{12}C+^{159}Tb$ and $^{16}O+^{159}Tb$ systems, at the Inter-University Accelerator Center (IUAC), New Delhi, India using recoil-catcher technique followed by offline γ-spectroscopy has been used to obtain the fusion cross-sections. The details of the experiments are given elsewhere [3, 4].

The experimentally measured total fusion cross-section for $^{12}C,^{16}O+^{159}Tb$ systems have been compared with that for $^{6,7}Li,^{10,11}B+^{159}Tb$ systems. However, a comparison of total fusion cross-sections for these widely different projectiles is not justified unless the geometrical and Coulomb effects are not removed. These effects may be eliminated with the renormalization of total cross-section and centre of mass energy [6]. However, it has been recently pointed out [5] that the above mentined reduction procedure may not completely remove dynamical and static effects arising due to height V_B, radius R_B and curvature $\hbar\omega$ of the Coulomb barrier, on the total fusion cross-sections at energies below and above the Coulomb barrier. A large value of $\hbar\omega$ implies that potential drops rapidly as the system moves away from the barrier radius. As such, the transparency of the barrier may change with $\hbar\omega$. The values of the barrier curvature parameter alongwith barrier radius 'R_B', potential barrier 'V_B' and α-seperation energy 'Q_α', for the systems studied for comparison are given in table 1. In order to account for the static effects the experimental fu-

*Electronic address: phy.vijayraj@gmail.com

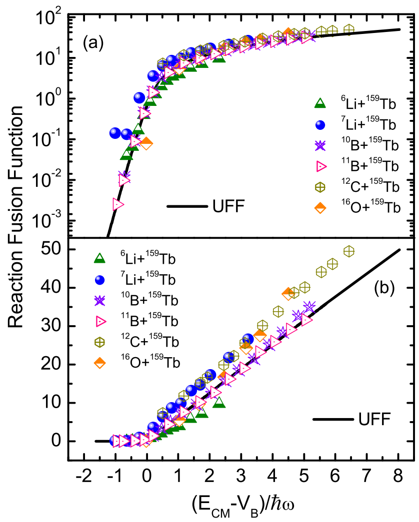

FIG. 1: Comparison of modified reaction fusion function (RFF) with UFF for several systems in (a) logarithmic and (b)linear scales.

sion cross-sections 'σ_F^{exp}' are reduced using the prescription given in ref. [5]. The dimensionless function, F$_{exp}$(x)=$(2E_{CM}\sigma_F^{exp})/(\hbar\omega\ R_B^2)$ has been computed as a function of normalized centre of mass energy x=$(E_{CM}-V_B)/\hbar\omega$. As per the Wong's formalism [7], F(x) can be written as $ln[1+exp(2\pi x)]$, which is independent of the system properties and is same for any system. Due to this characteristic, the function 'F(x)' is referred to as Universal Fusion Function (UFF) [5]. As a matter of fact, UFF can be used as a tool to assess the influence of channel couplings on the fusion. However, this reduction method has two difficulties, (i) Wong's approximation is not valid for light systems at sub-barrier energies and (ii) break-up effects on fusion are not clear i.e., the effect of coupling to continuum states. To compensate for the above Canto *et al.* [5], introduced a modified dimensionless reaction fusion function (RFF) as, F$^m_{exp}$(x)=F$_{exp}$(x)$[\sigma_w/\sigma_{CC}]$ where, 'σ_w' is the cross-section value predicted by Wong's formalism [7] and 'σ_{CC}' is the coupled channel (CC) cross-section. In Fig. 1(a & b), the deduced reaction fusion function F$^m_{exp}$(x) has been plotted respectively on the log and linear scales. Since, on the log scale [Fig. 1(a)] the data points at higher energy side are compressed together, the same graph is plotted in Fig. 1(b) on the linear scale to see the differences, if any, due to dynamical effects. A comparison of UFF with the RFF shown in Fig. 1(b) indicates that RFF for strongly bound ^{12}C and ^{16}O projectiles are deviated with relatively higher slope as compared to UFF line. The enhancement of the measured RFF as compared to UFF at the above barrier energies for the presently studied ^{12}C,^{16}O+^{159}Tb systems shows that the breakup of these projectiles is responsible for an appreciable part of the total fusion cross-section. Further, the α- seperation energies may be used to explain the projectile break-up in a systematic way and will be presented.

TABLE I: Empirical parameters for the presently studied systems.

Systems	R_B (fm)	V_B (MeV)	$\hbar\omega$ (MeV)	Q_α (MeV)
^{16}O+^{159}Tb	11.22	63.16	5.05	7.16
^{12}C+^{159}Tb	10.96	48.37	5.09	7.36
^{11}B+^{159}Tb	10.89	40.55	4.87	8.65
^{10}B+^{159}Tb	10.83	40.82	5.13	3.90
^{7}Li+^{159}Tb	10.56	25.05	4.81	2.40
^{6}Li+^{159}Tb	10.46	25.28	5.23	1.52

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