A study of fusion suppression in ^{12}C, ^{19}F + ^{159}Tb systems: Modified fusion function approach

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Introduction

In recent years, there has been substantial progress in understanding the dynamics of heavy-ion (HI) induced fusion reactions, which is crucial for producing and studying exotic nuclei [1]. A notable reduction in fusion cross sections has also been observed in HI reactions, primarily due to projectile breakup [2]. This phenomenon necessitates a thorough investigation into HI fusion reactions to understand the impact of breakup on the fusion process. Several studies have reported incomplete fusion (ICF) reactions, where the projectile fragments upon collision at energies slightly above the Coulomb barrier. The projectile break-up significantly suppresses the complete fusion (CF) cross section for both weakly and strongly bound projectiles. The suppression is closely related to the breakup threshold energy of the projectile in ICF reactions. Thus, at low energies, CF and breakup fusion reactions not only coexist but also compete with each other. In CF 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, ICF occurs, when only a part of projectile fuses with the target nucleus and remaining part escapes with nearly incident beam velocity. Several theoretical models [3] have been developed to understand the reactions dynamics of BUF, which are found to be reliable upto some extent only at energies ≥ 10.5 MeV/nucleon, but these models could not explain the ICF data at energies ≈ 4-7 MeV/nucleon. In addition to this, most of the BUF 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 [2,3]. Therefore, in the present work an attempt has been made to compare the effect of projectile structure of ^{12}C and ^{19}F, if any, on the BUF reactions on the same target ^{159}Tb within the framework of Universal fusion function (UFF).

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Experimental details

In one of our recent experiments performed at IUAC, New Delhi on the ^{19}F + ^{159}Tb system a significant contribution of break-up fusion of the projectile, at low energies has been observed [3]. The study focused on the measurement and analysis of the excitation function (EFs) of reaction residues at energies ≈ 4–6 MeV/nucleon. The ^{19}F beam was focused on self-supporting ^{159}Tb target (thickness ≈ 1.5mg/cm^2). To cover the wide range of energy, stacked foil activation technique followed by off-line γ-ray spectroscopy has been used. The detailed information of experiments may be found elsewhere [3].

Results and Conclusions

The analysis of EF's is done within the framework of statistical model code PACE4 [3]. The experimentally observed EFs of α-emitting channels are significantly found to be higher as compared to those obtained from PACE4 code.

This clearly manifests that the observed enhancement in EFs indicate the contribution of ICF reactions at studied range of energies. For a comparative study of projectile structure, two systems $^{12}C^{\alpha\text{-cluster}}$ + ^{159}Tb [2] and $^{19}F^{(\text{non } \alpha\text{-cluster})}$ + ^{159}Tb [3] have been analyzed within the Universal Fusion Function (UFF) approach [4]. This UFF approach effectively eliminates the geometric and static effects of the potential between colliding nuclei. The reaction cross-section has been reduced to fusion function F(x) and energy as;

$$\sigma_F \rightarrow F(x) = (2E_{cm}/\hbar\omega R^2)\, \sigma_F$$

$$x \rightarrow E_{cm} = (E_{cm} - V_b)/\, \hbar\omega$$

where $\hbar\omega$ is the barrier curvature.

The fusion function F(x) has been deduced for ^{12}C and ^{19}F and it is shown in Fig.1. From the above analysis, it has been observed that the fusion for ^{19}F is significantly suppressed to ≈30% below the UFF, while for ^{12}C, the suppression is around ≈12%. This observed suppression suggests the occurrence of prompt break-up of the projectiles ^{12}C and ^{19}F, where a portion of the flux is directed towards BUF reactions. The difference in the fusion suppression with respect to UFF for both projectiles is due to different α-break-up threshold energies i.e., $E_\alpha(^{12}C)$ = 7.37MeV and $E_\alpha(^{19}F)$ = 4.01MeV. However, to eliminate the coupling effects, if any, the fusion function *F(x)* is renormalized to obtain the modified fusion function (MFF) as $F^{MFF} \rightarrow \boldsymbol{F}_{expt} = F_{expt}(\sigma^F_W / \sigma^F_{CC})$, where σ^F_W is the fusion cross section calculated by the Wong approximation of 1DBPM [4] and σ^F_{CC} is the cross section obtained with coupled-channel calculations code CCFULL [4]. It may be pertinent to mention that, MFF is identical to UFF in the ideal case where all the channel coupling effects are contained in σ^F_{CC}. The deduced MFF for ^{12}C and ^{19}F projectile is presented in Fig.2. As can be seen from this figure, the suppression for α-cluster beam ^{12}C has now been reduced to ≈ 8% as compared to ≈ 20% for non α-cluster projectile ^{19}F. The observed suppression clearly indicating the influence of coupling through the break-up channels in both systems. Further details of measurement and analysis will be presented.

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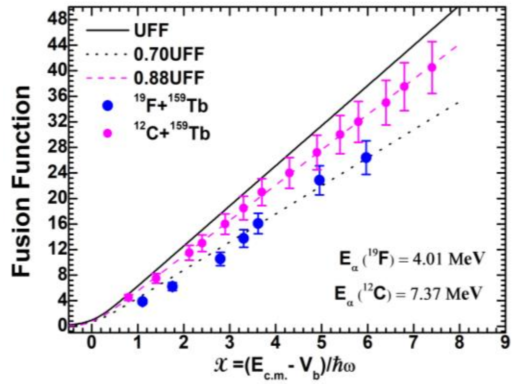

Fig.1: The fusion function plotted for ^{12}C and ^{19}F projectile on same target ^{159}Tb. The solid black curve is the benchmark UFF. The dotted blue and magenta lines are the UFF multiplied by 0.70 and 0.88.

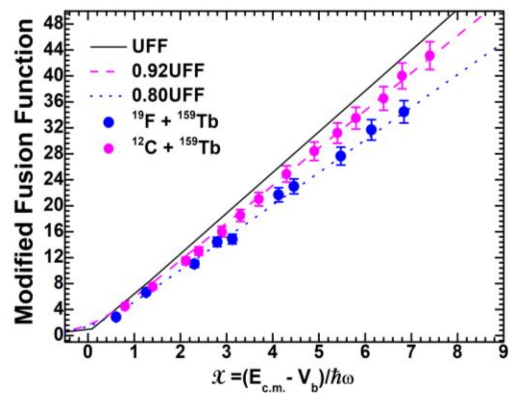

Fig.2 The modified fusion function (MFF) plotted for ^{12}C and ^{19}F projectile on same target ^{159}Tb. The solid black curve is the benchmark UFF. The dotted blue and magenta lines are the UFF multiplied by 0.80 and 0.92.

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