Study of incomplete fusion dynamics in the light of critical angular momentum and universal fusion function.

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Introduction

Heavy ion induced reactions are of particular interest especially about the complete fusion (CF) and incomplete fusion (ICF) at energies greater than or comparable to the coulomb barrier [1,2]. If the whole projectile merges with the target nucleus, leading to a complete transfer of incident momentum to the resulting compound system, it is called direct complete fusion (DCF). Contrarily, in the periphery of target nuclear field, the incident projectile may break into fragments, thus opening a chain of new reaction channels. When all the breakup fragments of the incident projectile amalgamate with the target nucleus one after the other, the process is called sequential complete fusion (SCF). The other possibility is that only a part of the incident projectile fuses with target (partial transfer of incident momentum), that is called the incomplete fusion (ICF) process. If none of the breakup fragments are able to get fused with the target nucleus, this leads to non-capture breakup (NCBU) process.

Experimental Details

The experiment was performed at the Inter University Accelerator Centre (IUAC), New Delhi, using thin target foils of ^{89}Y having thickness ≈200μg/cm^2 which has been evaporated on Al backing of thickness 1.92mg/cm^2. By weighing and α-transmission method, the thickness of target and Al catcher foils was determined. The $^{16}O^{7+}$ beam of ≈ 105 MeV energy was used for irradiation in the general purpose scattering chamber (GPSC), having an in-vacuum transfer facility. In order to catch the residues populated through CF and/or ICF, a stack of 14 Al-catcher thin foils (thickness ranging 93-144μg /cm^2) was placed just behind the target. Taking into account the half-lives of the populated evaporation residues (ER$_s$, the target was bombarded with the projectile for ≈9 hours with a beam current of 27nA. An electron suppressed Faraday cup placed behind the target-catcher assembly was used to measure the beam current. After the irradiation, counting of activity of the populated ER$_s$ trapped in different catcher foils was performed using a High-Purity Germanium detector (HPGe) coupled to a CAMAC based CANDLE software.

Results and Discussion

In the present work, the sum rule model proposed by Siwek-Wilezynska et al has been used to analyse the role of angular momentum in deciding the fate of compound nucleus formation through the CF or ICF process. As per the sum rule model, ICF reaction occurs only if the angular momentum of the incident projectile is greater than critical angular momentum. The CF cross section of the colliding system is given by:$\sigma_{CF} = \pi\hbar^2/(2\mu E_{c\cdot m}) \sum_{l=0}^{l_{crt}}(2l+1)T_l$. A sharp cutoff approximation is assumed as;$T_l = 1(for\ l \leq l_{max})$ and $T_l = 0(for\ l > l_{max})$. Fig.1 shows the behaviour of sharp cut-off model along with the angular momentum distribution obtained using the code CCFULL for the ^{16}O + ^{89}Y system at $E_{lab} \cong$ 105 MeV. The statistical model code PACE4 was used to account for the cross- section of the missing CF channels. The ratio $R = \sum\sigma_{xn+pxn}^{PACE4}/\sigma_{fus}^{PACE4}$ was calculated by using the code PACE 4, and using this the experimental CF cross section was calculated as

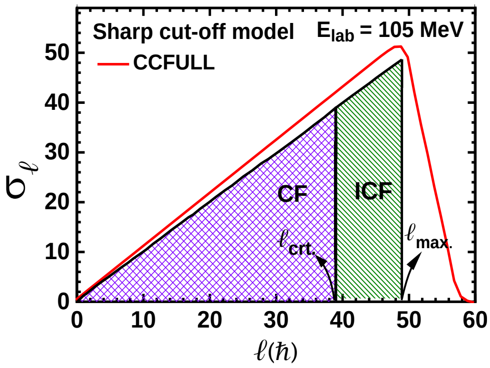

Fig.1 Sharp cut-off approximation and predicted angular momentum distribution for the $^{16}O+^{89}Y$ system.

$\sigma_{CF}^{expt} = \frac{\Sigma\sigma_{xn+pxn}^{expt}}{R}$. The value of σ_{CF} used in the calculations of l_{crt} and $l_{\max}$ as well as in the calculation of fusion function and ICF probability is based on statistical model code PACE4. Using the instructions of Wilczynska et al the value of l_{crt} was found to be 39$\hbar$. This value of l_{crt} was found to be in close approximation with the l_{crt} (38$\hbar$) value extracted from σ_{CF} using sharp cut-off approximation. The estimated value of $l_{\max}$ by CCFULL and PACE 4 calculations (49$\hbar$) as well as by the sharp cut-off approximation (=49$\hbar$) was found to lie amply above the l_{crt} value which suggests the peripheral nature of ICF process observed in the ^{16}O + ^{89}Y reaction at $E_{lab} \cong 105MeV$.

Universal Fusion Function:

Many entrance channel parameters were found to affect the extent of ICF contribution to the TF (total fusion) cross-section. The coupled channels (CC) calculation carried out using the code CCFULL does not take into consideration the breakup of the incident projectile and as a result the CF cross-section is supressed [3,4]. However, CCFULL calculations completely reproduce the TF cross-section. It was found that the $E_{B.U}$ (breakup threshold energy) value of the incident projectile directs the degree of fusion suppression. Thus, the dimensionless physical quantities -fusion function $F(x)$, and x have been developed to approximate the degree of fusion incompleteness in ^{16}O over different targets. $F(x) = \frac{2E_{c.m.}}{R_b^2\hbar w}\sigma_{CF}, x = \frac{(E_{c.m.}-V_b)}{\hbar w}$. Simplification of the Wong formula gives: $F_0(x) = \ln[1 + \exp(2\pi x)]$, $F_0(x)$ is called the Universal Fusion Function (UFF).

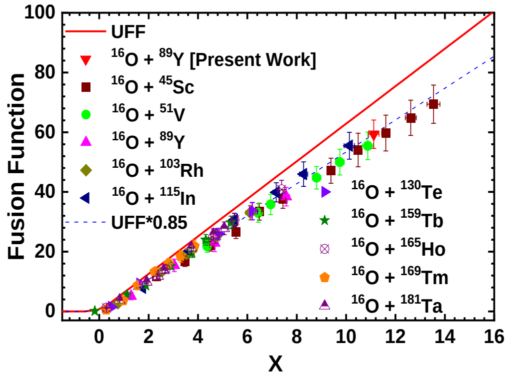

Fig.2 F(x) as a function of x for the α cluster projectile ^{16}O on different targets.

Thus, a systematics can be developed by comparing the CF cross-section data of different systems directly with the help of UFF. At energy above the coulomb barrier, inelastic excitation and transfer channel coupling are not so effective, so any departure of experimental fusion function from UFF is credited to the projectile breakup on CF cross-sections. Fig.2 illustrates the fusion function F(x) for the α cluster projectile ^{16}O over different targets, namely ^{45}Sc, ^{51}V, ^{89}Y (present work), ^{103}Rh, ^{115}In, ^{130}Te, ^{159}Tb , ^{165}Ho ,^{169}Tm and ^{181}Ta, as a function of x [5]. The most favourable break up channel for ^{16}O projectile is $^{16}O \rightarrow ^{12}C+\alpha$, having breakup threshold energy ($E_{B.U}$) value of 7.16 MeV. The solid line in figure 2 represents the UFF. Fig.2 shows the CF fusion function suppression with respect to UFF for all the systems. This suppression in $F(x)$ with reference to UFF is expected to arise from breakup of ^{16}O projectile into fragments due to its low $E_{B.U}$ value.

References

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