

Investigating the Influence of Incomplete Fusion on Complete Fusion of ^{16}O –Induced Reaction $\approx 3\text{-}8$ MeV/nucleon

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Abstract

The dynamics of heavy-ion fusion reaction elaborate in the interaction of ^{16}O projectiles with ^{165}Ho and ^{51}V targets at $\approx 3\text{-}8$ MeV/nucleon specific energies were studied. This study were emphases on the relationship between entrance channel belongings and incomplete fusion reaction. The experimentally measured excitation functions of various reaction products duplicated by complete or incomplete fusions of $^{16}\text{O} + ^{51}\text{V}, ^{165}\text{Ho}$ projectile-target systems had been compared and analyzed within the predicted excitation functions, using the statistical model code PACE4. For α -emitting channels in the present systems, the measured excitation functions had been highest than the predictions of the theoretical model code, which may focuses at these energies. However for non-alpha emitting channels in this system the measured excitation function had been nice agreement with the theoretical values. An endeavor were made to nearly the incomplete fusion fraction that designates importance of incomplete fusion process.

Keywords: Alpha emitted, CF reaction, Entrance channel, Heavy ion fusion, ICF reaction, Non alpha emitted

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1. Introduction

Study of different mechanism elaborate in heavy ion induced reaction, complete fusion, incomplete fusion and direct reaction have been point of interest even at low energies [1]. Thus, the study of heavy ion interactions is quite specific due to its complex structure and large momentum carried, and heavy ion interactions may be categorized in many ways, one of them is in terms of impact parameter. The direct reactions play an important role at higher values of impact parameter, leading to few nucleon transfer processes. However, at smaller values, complete fusion (CF) reaction in which Projectile is completely fused with the target nucleus and highly [2]. Complete fusion (CF) reaction process of the projectile with the target, the projectile completely fuses with target nucleus. And, the entire momentum of the projectile is transferred to the target nucleus. In the case of incomplete fusion reaction, only a part of the projectile fuses with the target nucleus and the rest of it is going into the beam direction with almost the same velocity as that of incident ion beam [3, 4]. Current experimental studies have been shown that significant ICF impact even at energies just beyond Coulomb barrier [5].

The finding have encourage of various researcher in the filed to consider ICF at comparatively low bombarding energies. Suprnasody *et al* [6] investigated effect of entrance channel parameters on the fusion of $^{16}\text{O} + ^{66}\text{Zn}$ and $^{37}\text{Cl} + ^{45}\text{Sc}$ system.

Abhishek *et al* [7] studied effect of entrance channel properties in the incomplete fusion of $^{12}\text{C} + ^{159}\text{Tb}$ at energies $\approx 4\text{-}7$ MeV/A. The results indicated that incomplete fusion contribution found to be sensitive to the projectile type, energy and entrance channel mass-asymmetry. Pushpendra *et al* [8] studied the dynamics of incomplete fusion by spin dissemination of $^{16}\text{O} + ^{169}\text{Tm}$ system at ≈ 5.6 MeV/nucleon. The result showed that the measured normalized production yields of fusion-evaporation xn/ α xn-channels related agreement within the predictions of theoretical model code PACE4. The work covenants with enquiry of incomplete fusion reaction and entrance channel effect in the interaction of $^{16}\text{O} + ^{51}\text{V}$, and $^{16}\text{O} + ^{165}\text{Ho}$ systems at $\approx 3\text{-}8$ MeV/nucleon. On behalf of predictions of the measured excitation functions are equated through hypothetical model code PACE4 resolve be used at 100000 cascades and the Morgenstern *et al* [9] efficient used to isolated out ICF influence.

2. Formulations and computer code

There are diverse computer codes to calculate the theoretical excitation functions. Those are PACE4, CASCADE, ALIC-91 AND COMPLET codes. Though, PACE4 expectations were found to be in decent covenant for complete fusion channels intended for the existing projectile-target system. And enquiry with computer code PACE4 within attention of Hauser-Feshbach formulation likewise argued in this section [10].

$$\sum \delta CF^{(theo)} = \sum \delta non - \alpha - emit^{(exp)} + \sum \delta \alpha - emit^{(theo)} \dots \dots \dots (1)$$

$$\delta_{TF}^{(exp)} = \sum \delta CF^{(theo)} + \sum \delta_{ICF} \dots \dots \dots (2)$$

Since the cross-section of ICF

$$\sum \delta_{ICF} = \delta_{TF}^{(exp)} - \sum \delta CF^{(theo)} \dots \dots \dots (3)$$

theoretical predication obtained from PACE4 for possible residues populated in reaction. Cross-section are

deduced using Morgenstern et al [10].

$$\sum \delta CF^{(theo)} = \sum \delta non \alpha - emit^{(exp)} + \sum \delta \alpha - emit^{(theo)} \dots\dots\dots (1)$$

$$\delta_{TF}^{(exp)} = \sum \delta CF^{(theo)} + \sum \delta_{ICF} \dots\dots\dots (2)$$

From this cross-section of ICF

$$\sum \delta_{ICF} = \delta_{TF}^{(exp)} - \sum \delta CF^{(theo)} \dots\dots\dots (3)$$

The ICF fraction which tells the contribution of ICF in the total process is calculated

$$P_{ICF}(\%) = \frac{\sum \delta_{ICF}}{\delta_{TF}} \times 100 \dots\dots\dots (4)$$

To see the correlations between the deduced incomplete fusion fraction and entrance channel properties (normalized projectile energy, mass-asymmetry and projectile structure) Instead of projectile energy (E_p) we used the normalized projectile energy (E_p/V_{CB}) that swallowed the effect coming from different coulomb barrier.

$$V_{CB} = \left[\frac{Z_p Z_T}{A_p^{\frac{1}{3}} + A_T^{\frac{1}{3}}} \right] \dots\dots\dots (5)$$

To see the correlation between P_{ICF} with normalized projectile velocity (V_{rel}/c)

$$V_{rel} = \sqrt{\frac{2(E_{cm} - V_{CB})}{\mu_A}} \dots\dots\dots (6)$$

Where $\mu_A = \frac{A_p A_T}{A_T + A_p}$ And $E_{cm} = \frac{A_T}{A_T + A_p} E_{lab}$.

2.1 Result and discussion

A) $^{16}O + ^{165}Ho$ System

The leisurely excitation functions and hypothetical estimated gained from PACE4 for ^{176}Re residue duplicated through ($^{16}O, 5n$) channel is shown in Fig. 1.1 (a). in this channel, there is no chance ICF reaction, and therefore, this channel is formed only by CF process. It may be perceived that from Fig. 1.1 (a) the theoretically calculated excitation functions intended for level density constraint $K = 12$ in over-all manufactured respectable the experimentally leisurely excitation functions intended for the residue ^{178}Re formed in the CF ^{16}O projectile through ^{165}Ho target.

The measured CF cross-sections on behalf of a illustrative non- α -emitting (non- α -emit) channels in system, $^{16}O + ^{16}Ho$, could be duplicated full filed by PACE4 estimates, gives the contribution parameters preferred to full filed the EFs of all either non- α and α - emitting channels deliberated in the, $^{16}O + ^{16}Ho$ system. Fig. 1.1 (b) exposed the measured cross-sections for the illustrative ($^{16}O, \alpha 3n$) channel. As can be seen from Fig. 1.1 (b) the experimentally leisurely EFs are relatively higher as associated to the theoretical estimates. Meanwhile the code PACE4 didn't take ICF into form, consequently the augmentation in the experimentally measured cross-sections are attributable to the influences of ICF of ^{16}O with ^{165}Ho target.

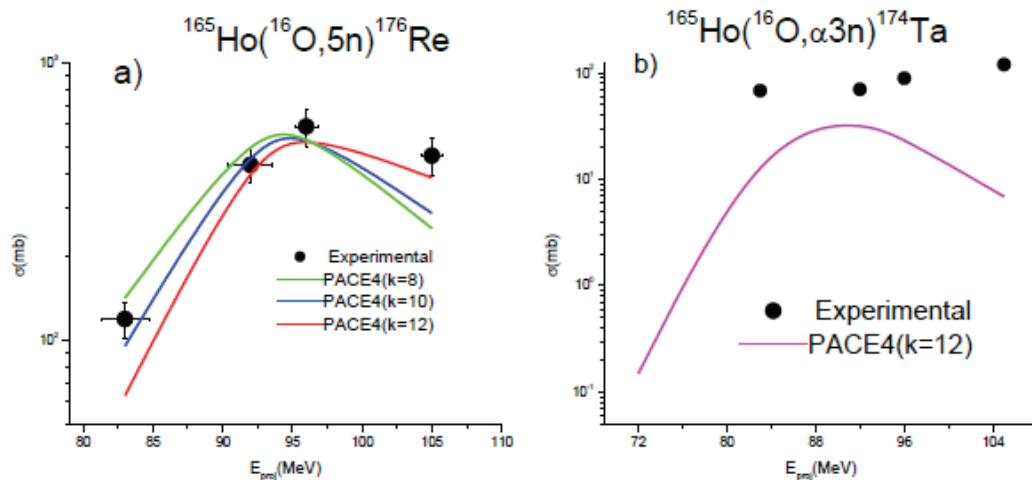


Fig.1.1: (a) Summation of leisurely EFs for all CF channels lengthways with PACE 4 calculations for (^{16}O , 5n) and (b) alpha-radiated channels (^{16}O , $\alpha 3n$) system.

B) For $^{16}\text{O} + ^{51}\text{V}$ system

In Likewise way, in $^{16}\text{O} + ^{51}\text{V}$ system values of the near density parameter (K=8, 10, 12) were diverse to fulfill the experimentally measured EFs for a illustrative non- α -emitting (^{16}O , p4n) channel. Fig. 1.2 (a) displayed the experimentally measured and theoretically calculated EFs for ^{62}Zn remainder reproduced through (^{16}O , p4n) channel. In this channel also there is ICF reaction happening and hence, this channel is produced only by CF process. As can observing from the figure, the PACE4 estimation with K=10 in general reproduced agreeably the experimentally measured EFs. For all possible channels in the interaction $^{16}\text{O} + ^{51}\text{V}$ system all calculations and examination were done constantly using K=10. The measured EFs beside with the PACE4 prediction for illustrative residue inhabited through α -emitting channel is shown in Fig. 1.2 (b). Illustrative ^{54}Mn residue may yield through CF or ICF processes as:

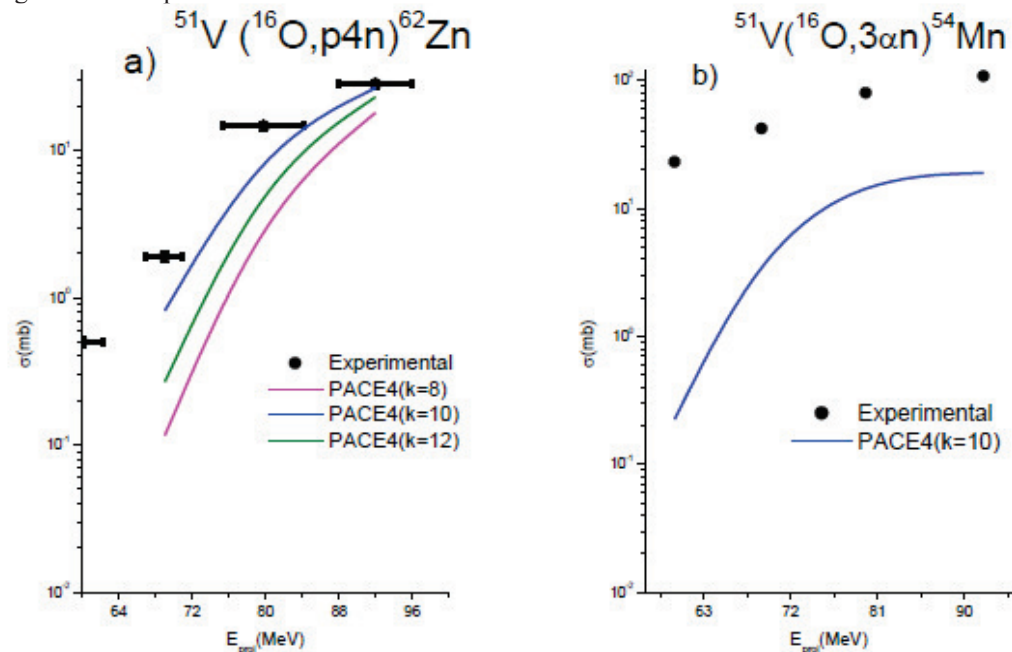


Fig.1.2: (a) measured EFs for (^{16}O , p4n) channels beside with PACE4 predication and (b) alpha emitted channels for (^{16}O , 3 αn) system

2.1 Incomplete fusion influences

In this section an aim has been made to distinguish out the influences of ICF in all α -emitting channels formed in the interfaces of, ^{16}O projectiles with, ^{51}V and ^{165}Ho targets. The totality of the ICF cross-section for the corresponding systems, $\sum \delta_{ICF}$, were assigned to the distinguish between the higher charged precursor decay related measured cross-section for conceivable α emitting channels, $\sum \delta \alpha^{(exp)}$ and the calculated cross-section $\sum \delta \alpha^{(theo)}$ for preeminent fitted K value. It is obviously seen in Fig. 1.3 from (a) to (b) that ICF production cross-section $\delta_{ICF} = \sum \delta \alpha^{(exp)} - \sum \delta \alpha^{(theo)}$ increase directly through increase projectile energy.

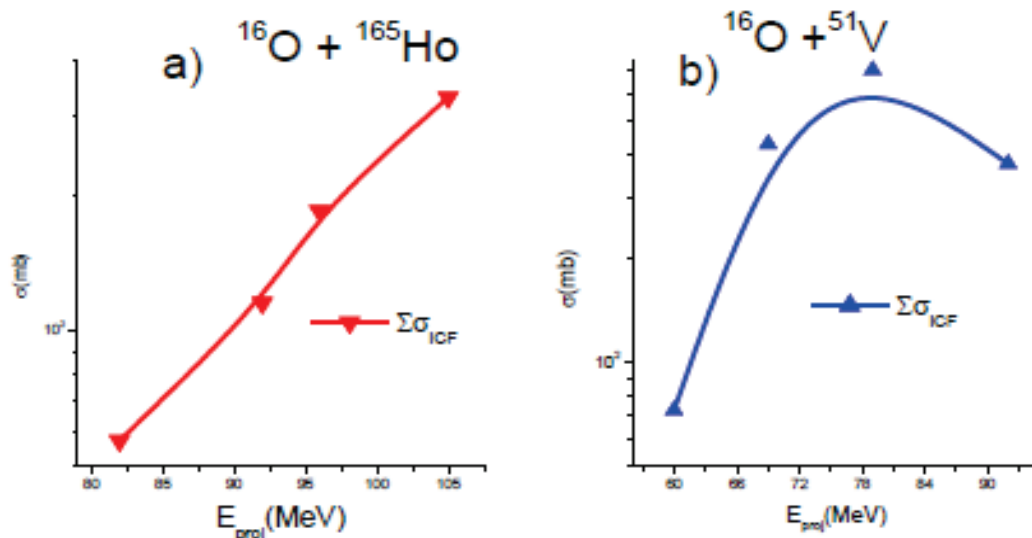


Fig.1.3: $\sum \delta_{ICF}$ versus E_{proj} . It has been declared that all the α -emitting channels identified in the present systems are expected to have direct influences from ICF reactions.

Fig. 1.3 (a) and (b) demonstrated the sum of influences coming from all ICF channels $\sum \delta_{ICF}$ and the sum of all CF channels $\sum \delta CF$ was plotted along with the total fusion cross-section $\sigma_{TF} = \sum \delta_{ICF} + \sum \delta CF$ for all α and non- α emitting channels in $^{16}\text{O} + ^{51}\text{V}$, ^{165}Ho systems. As can be observed from this figure the CF constituents have established influence up to $\approx 70\text{MeV} \approx 72\text{ MeV}$, and $\approx 75\text{MeV}$ for $^{16}\text{O} + ^{51}\text{V}$, systems, correspondingly, whereas ICF contribution looks start to influence from this points. Additional, except for $^{16}\text{O} + ^{165}\text{Ho}$ system it is obviously seen from this figures that the farewell between the plots of $\sum \delta_{ICF}$ and $\sum \sigma_{TF}$ usually declines directly from this points with an increase projectile energy, which exhibited that the ICF contribution becomes higher at higher energy points in the corresponding systems.

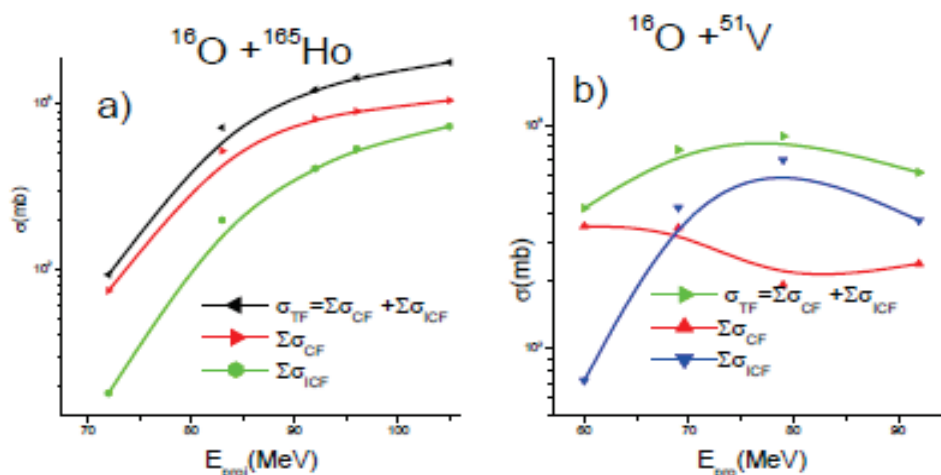
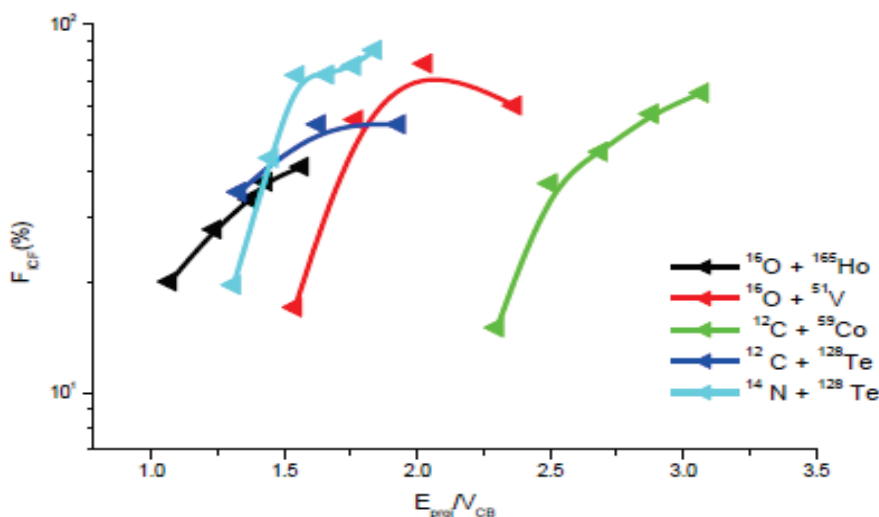


Fig.1.4: The overall totality of the measured, σ_{TF} and the total sum of the CF cross-sections, $\sum \delta_{CF}$ beside with the total sum of ICF cross-sections, $\sum \delta_{ICF}$ at numerous energies.

In order to study the necessity of ICF influence on numerous entrance channel constraints, the percentage ICF fraction (FICF) is deliberate by using the following formula

$$P_{ICF}(\%) = \frac{\sum \delta_{ICF}}{\delta_{TF}} \times 100 \dots \dots \dots (4)$$

Fig.1.5: FICF values as a function of normalized projectile energy. It may be perceived from this figure the incomplete fusion fraction (FICF) which signifies a part of ICF contribution to all fusion processes, for all systems except $^{16}O + ^{51}V$ usually well increases within the increase normalized projectile energy.



Conclusion

In this study the excitation functions of residues formed in the interaction of $^{16}O + ^{51}V$, $^{16}O + ^{16}Ho$ system had been investigated at $\approx 3-8$ MeV/nucleon with the intention of contract the relationship between entrance channel belongings and incomplete fusion reaction. The measured data had been compared within calculation done by using the statistical model code PACE4. For non- α -emitting channel from the systems, the experimental measured excitation functions, after adjusting them for may be possible contributions from higher charger isobaric precursor decays, have had been generally found in nice covenant with theoretical predications.

On the other hand, for α -emitting channels, the measured excitation had been straight higher than the values expected by PACE4. This highly raise may be displayed the processes from the break-up effect. For $^{16}O +$

^{16}Ho system, the predictable ICF fraction had been established to be less than, nearby 20.2% at the initial point or at minimum energy of the reaction but at the higher energy point it was extended nearby, 41% of the overall fusion cross-section. Even though, the ICF fraction had been found to be nearby 19.5% of the total cross-section at the initial energy of ICF influence and reached $\approx 84.9\%$, at the higher energy point for $^{16}\text{O} + ^{51}\text{V}$, systems. From the present investigation, it is established that the fraction of ICF increase directly increase within projectile energy.

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