Influence of Mass-Asymmetry on Incomplete Fusion

Rahbar Ali[1*], D. Singh[2], M. Afzal Ansari[1♣], Harish Kumar[1], Rakesh Kumar[2], M. H. Rashid[3], K. S. Golda[1], S. Muralithar[2], R. P. Singh[2], R. Guin[3] S. K. Das[3] and R. K. Bhowmik[2]

[1]*Department of Physics, Aligarh Muslim University, Aligarh – 202 002, India*

[2]*Inter-University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi – 110 067, India*

[3] *Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata-700 064, India*

During the last few decades, fusion process in heavy ion induced reaction at energies near and above the Coulomb barrier has been extensively studied. At energies not too much above the barrier, the fusion process plays an important role in reaction dynamics. The widely used model PACE-2[1], describes the fusion cross-section. While at higher energies, fusion process gives the way to incomplete fusion (ICF), where projectile fragmentation takes place and decreasing the reaction cross-section corresponding to the fusion. The ICF cross-section as a function of entrance channel mass-asymmetry has been explained in terms of the model based on the interaction barrier, critical angular momentum and critical distance of approach [2]. In case of ICF, an incompletely fused composite system is formed, where partial linear momentum of the projectile is given to the target nucleus and relatively less nucleonic degrees-of-freedom are involved as compared to CF. This incompletely fused composite system having less charge and mass in-comparison to completely fuse composite nucleus. However, first experimental evidence for ICF process was observed by Britt and Quinton [3] who observed the break-up of the incident projectiles like ^{12}C, ^{14}N and ^{16}O into alpha clusters in an interaction with the target nucleus at energy ≈ 10.5 MeV/A. Parker *et al.,* [4] observed ICF in the reactions at ~ 8 MeV/nucleon ^{12}C-beam on ^{51}V by measuring the forward peaked α-particles in the energy spectra and angular distribution of α-particles. Tserruya *et al.,* [5] also found evidence for ICF process from time-of-flight measurements of evaporation residues (ERs) in a reaction of 5-10 MeV/nucleon ^{12}C-beam with ^{120}Sn, ^{160}Gd and ^{197}Au. ICF studies using loosely bound projectiles have also been done by Gomes *et al.,* [6].

The mass-asymmetry measurements have been carried out by using ^{20}Ne and ^{16}O-ion beam delivered from VECC (Kolkata) and 15UD Pelletron (New Delhi). The details of the experimental set-up are shown somewhere else [7]. Activation technique has been used for the present measurement. In this technique, stack of targets viz; ^{55}Mn, ^{159}Tb and ^{156}Gd along with Al-catcher foils have been used. For the above measurement, targets of ^{55}Mn, ^{159}Tb and ^{156}Gd were prepared by rolling machine and/or evaporation technique and thickness of these samples were measured by electronic balance and α-transmission method and thickness of the samples comes out to be in the range ~1.0-2.5μg/cm^2.

The ICF fraction may be defined as, $[\sum\sigma_{ICF} / (\sum\sigma_{CF} + \sum\sigma_{ICF})]$. It has been deduced ICF-fraction for all the three projectile-target systems ^{20}Ne + ^{55}Mn [7], ^{20}Ne + ^{159}Tb [8] and ^{16}O + ^{156}Gd [8] and found that ICF-fraction increases with projectile energy. Moreover, the ICF fraction for ^{20}Ne + ^{55}Mn comes out to be ≈ 2 % of total fusion cross-section σ_{TF} at ~ 51 MeV energy, which increases with projectile energy and approaches to ~ 49 % of σ_{TF} at projectile energy ~164 MeV. Similarly, energy dependence of ICF fraction for ^{20}Ne + ^{159}Tb system has been estimated, whereas ICF fraction is ~ 5.6% of σ_{TF} at ~ 95 MeV projectile energy

* Eleactronic Address: rahbarali1@rediffmail.com

♣ Electronic Address: drmafzalansari@yahoomail.com

and it approaches to 49% of σ_{TF} at the highest projectile energy ~ 164 MeV. As such, for ^{16}O + ^{156}Gd system, ICF fraction at ~ 68 MeV projectile energy is ~ 7 % of σ_{TF} and at ~ 98 MeV energy it has been estimated to be ~ 48% of σ_{TF}. It may be observed that percentage of ICF contribution approaches the same value for ^{20}Ne + ^{55}Mn and ^{20}Ne + ^{159}Tb systems at higher energy. This may be because of the fact that effect of Coulomb barrier diminishing as projectile energy increases.

It has been suggested by Morgenstern *et al.,* [9] that the onset of the ICF process, interacting nuclei approach each other with the relative velocity (V_{rel}) given by;

$$V_{rel} = \sqrt{\frac{2(E_{CM} - V_B)}{\mu}}$$

where, μ is the reduced mass of the system, E_{CM} is the centre-of-mass energy and V_B is the Coulomb barrier between two interacting partners.

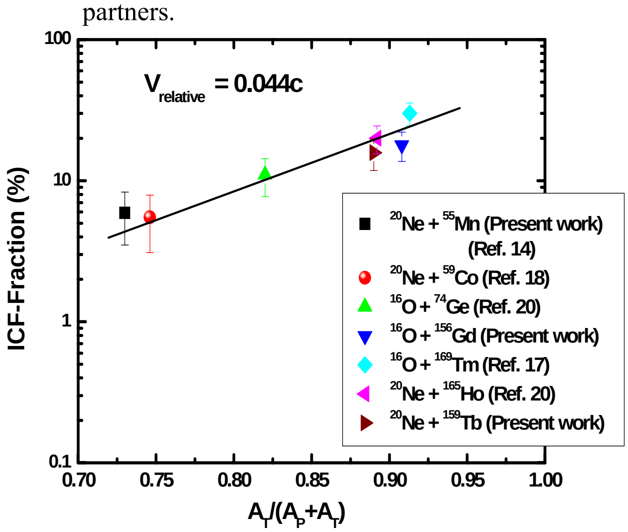

Fig.1: Variation of the ICF-fraction as a function of mass-asymmetry between projectile and target at a constant value of V_{rel} = 0.044c for different systems.

This expression takes into account the difference in Coulomb barrier between each two interacting partners. Using Coulomb barriers for the interacting partners, the incomplete fusion fraction has been deduced for the present systems at the same relative velocity V_{rel} =0.044c and have been plotted along with the previously measured systems: ^{16}O + ^{74}Ge [10], ^{16}O + ^{169}Tm [11], ^{20}Ne + ^{59}Co [12], ^{20}Ne + ^{165}Ho [12], as a function of mass-asymmetry [A_T /(A_T + A_P)] between various projectile-target systems and is shown in Fig.1.It is observed from this figure ICF fraction is sensitive to projectile energy and mass-asymmetry of the projectile-target systems and in general ICF probability is more in a mass-asymmetric system than in mass-symmetric system.

Authors are thankful to Directors of IUAC-New Delhi and VECC-Kolkata for providing necessary experimental facilities. The authors are also thankful to the Chairman, Department of Physics, A.M.U-Aligarh for providing the necessary facilities related with this work.

References:

[1] A. Gavron; Phys. Rev. C **21** (1980) 230.
[2] Ch. Ngo, Prog. Nucl. Part. Phys. **16** (1985) 139.
[3] H.C. Britt and A.R. Quinton, Phys. Rev. **124** (1961) 877
[4] D. J. Parker *et al*., Phys. Rev. C **30** (1984) 143.
[5] I. Tserruya *et al*., Phys. Rev. Lett. **60** (1988) 14.
[6] P. R. S. Gomes *et al*., Phys. Lett. B **601** (2004) 20.
[7] Rahbar Ali *et al.*, Journal of Physics G: Nucl. Part. Phys.; **37** (2010) 11510.
[8] Rahbar Ali, PhD Thesis, Aligarh Muslim University, Aligarh, India, 2012.
[9] H. Morgenstern *et al*; Phys. Rev. Lett. **52** (1984) 1104; Z. Phys. A **313** (1983) 39; Phys. Lett. B **113** (1982) 463.
[10] D. Singh *et al.*, Chinese Journal of Physics **46** (2008) 27.
[11] P. P. Singh *et al.*, Phys. Rev. C **77** (2008) 014607.
[12] D. Singh *et al.*, Phys. Rev. C **83** (2011) 054604; Phys. Rev. C **79** (2009) 05460.