Dependence of Incomplete Fusion Reaction on Mean Input Angular Momentum

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Introduction

It has been well experimentally established that complete fusion (CF) and incomplete fusion (ICF) are the dominating modes of reaction at energies above the Coulomb barrier [1-2]. The different modes of reaction can also be understood on the basis of driving angular momenta imparted into the system. For CF to occur, entrance channel angular momentum should be such that $\ell \le \ell_{crit}$, the upper limit of angular momentum, where the projectile hugs the target nucleus with the involvement of all the nucleonic degrees of freedom at projectile energy above the Coulomb barrier. On the other hand, mean input angular momentum lying in the range $\ell_{crit} < \ell \le \ell_{\max}$, maximum angular momentum, where the projectile is break-up into the fragments, one part of the projectile fuses with target nucleus called participant and rest part moving in the forward direction as a spectator with almost same velocity as that of incident ion beam. It may be pointed out that multitude of driving angular momenta may vary with the projectile energy and/or with the impact parameter. However, there is no sharp boundary for the CF and ICF processes; both the processes have been observed below and/or above the limiting value of input angular momenta [3]. The most important issues about ICF reaction dynamics at energy ~5.6 MeV/ nucleon are localization of angular momentum window and possibility of populating high spin states. Hence, the study of ICF reaction dynamics is still an active area of investigation to get a clear picture about the multiplicity of input angular momentum associated with different reaction channels has been drawn. In order to get more information about the various degree of mean input angular momentum involved in various reaction channels associated with ICF reaction dynamics, a particle-γ coincidence experiment has been done out at IUAC, New Delhi-India.

Experimental Details and Interpretation of Results

The self-supporting target ^{160}Gd of thickness about 1.3 mg /cm^2 was mounted over the target ladder, situated at 45^0 with respect to the beam direction in the scattering chamber. The ^{160}Gd target was bombarded by $^{16}O^{+7}$ beam at energy ~5.6 MeV/nucleon with beam current ~ 25nA delivered from 15UD-Pelletron Accelerator at IUAC. In the forward direction, detectors were supposed to detect both (i) fusion-evaporation (CF) α-particles (of energy ~17 MeV), emitted from the decay of compound nucleus $^{176}Hf^*$ and (ii) ‘direct’ or ‘fast’ α-particles (of energy ~ 25 MeV), moving as spectator, associated with ICF of the projectile. As such, in order to record ‘direct’ or ‘fast’ α-particle originated from ICF reaction in forward cone, an Al-absorber of appropriate thickness (~ 100 μm) has been placed in front of each four charged particle detectors (CPDs), to stop the fusion-evaporation α-particles, produced in ‘CF’ so that only ‘direct’ or ‘incompletely fused’ α-particles may only be detected. The ^{16}O-ion beam was finally stopped on a thick tantalum sheet attached with faraday cup in the end of beam line. All the HPGe detectors were calibrated by using ^{133}Ba, ^{60}Co and ^{152}Eu-source of known strength. The efficiency of high resolution HPGe detector was measured by using ^{152}Eu-source. Moreover, ^{241}Am α-source has been used to calibrate the CPDA detectors.

From the measured spin distribution profiles of the ERs populated in CF and ICF reactions [4], it has been observed that the mean input angular momentum for ERs produced through CF reaction channels is found to be ≈ $7\hbar$, while the mean input angular momentum for ERs produced through ICF reaction in 'fast' α and 2α–emission channels in 'forward cone' of the CPDA, comes out to be ≈ $9\hbar$ and ≈ $11\hbar$ respectively. Present observations clearly show that the production of 'fast' α–particle(s) are at relatively higher input angular momentum and hence lead to peripheral interaction. An approximate relation has been obtained in terms of driving input angular momentum for CF and ICF reaction products with different α-multiplicity is,

$$\ell_{ICF-2\alpha xn} \approx 1.22\ell_{ICF-\alpha xn} \approx 1.56\ell_{CF-xn/\alpha xn}$$

The mean input angular momentum associated with xn, 1α and 2α-emission channels in forward direction have been plotted as a function of reaction mode and shown in Fig.1.

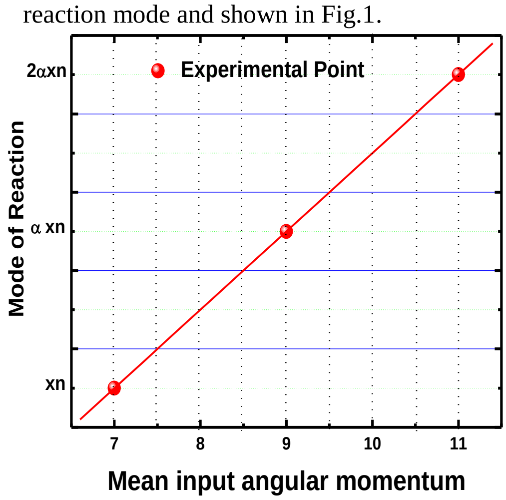

Fig.1:The typical plot shows the dependence reaction mode on mean input angular momentum for ^{16}O + ^{160}Gd system at energy, E ~ 5.6MeV/A.

This figure shows that more and more angular momentum is involved with incompleteness of the system. It may also be pointed out from Fig.1 that angular momentum associated with ICF reaction is larger than that of CF reaction. Thus ICF reaction can be used to produce the nuclei in high spin states, which can not be achieved via CF process.

Conclusions

With these experimental findings, we have concluded that the driving input angular momentum associated with ICF reaction products have been found to be relatively higher than that involved in the production of CF reaction products, and found to be increases with direct-α-multiplicity. It is also inferred that in ICF reaction products, mean input angular momentum increases with fusion incompleteness as compared to CF reaction products. The present observations clearly show that the production of 'fast' α–particle(s) are at relatively higher input angular momentum and hence leads to peripheral interaction. It is also observed that the multiplicity of 'fast' α-particles increases with the driving input angular momentum and shows the variation of ℓ-bins with different values of impact parameters at projectile energy ~5.6 MeV/nucleon.

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References

[1] Back *et al*; Rev. Mod. Phys. 86, 317 (2014).

[2] Canto *et al;* Phys. Rep. 424, 1 (2006)).

[3] I. Tserruya *et al*; Phys. Rev. Lett. **60**, 14 (1988).

[4] R. Ali *et al;* DAE-BRNS Symposium on Nucl. Phys. IIT Roorkee, India Vol. 53(2008) 371.