Investigation of Incomplete Fusion Dynamics at $\ell \leq \ell_{crit}$

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Introduction

Investigating incomplete fusion (ICF) of heavy ions (HI) with different targets has been gaining interest at energies beyond the Coulomb barrier. The experimental observations of HI induced reactions reveal that CF and ICF are the predominant nuclear reaction mechanisms at projectile energies above the Coulomb barrier [1]-[4]. In case of CF process, the projectile completely fuses with the target nucleus and the highly excited nuclear system decays by evaporating low energy nucleons and alpha particles. In the ICF process, which is characterized by the partial fusion of the projectile with the target, the projectile is assumed to break-up into two fragments and one of the fragments fuses with the target nucleus, while remnant moves in the forward direction [3]. Semi classical theory of HI interaction categorizes the CF and ICF processes on the basis of driving input angular momentum imparted in the system. In the CF process the driving input angular momentum lying in the range $0 < \ell \leq \ell_{crit}$ while in case of ICF process the driving input angular momentum lying in the range $\ell_{crit} < \ell \leq \ell_{max}$. Various theoretical models have been proposed for studying the dynamics of ICF. However, as of now, no theoretical model has been able to adequately explain the overall characteristics of experimental data below energy $\approx$ 10 MeV/nucleon. The literature lacks extensive comparative studies on the critical angular momentum (ℓ_{crit}) of medium mass target nuclei using heavy ions. In the current study, the impact of ℓ_{crit} on ICF dynamics has been analysed when the projectile energy $\approx$ 3-7 MeV/nucleon. The Sum-Rule model [5] and CCFUL [6] are utilized to interpret the fusion ℓ distribution window for the the system ^{14}N + ^{148}Nd at different energies.

Experimental Details

The experiment for the ^{14}N + ^{148}Nd system, at projectile energy above the Coulomb barrier, has been done by using General Purpose Scattering Chamber (GPSC) at Inter-University Accelerator Centre (IUAC), New Delhi, India. In the present study, stack-foil activation technique followed by offline γ-ray spectrometory has been used. Firstly, the $^{14}N^{6+}$ ion beam of energy $\approx$ 85 MeV was produced by pelletron accelerator to irradiate ^{148}Nd. The irradiation of 7 stacks consisting ^{27}Al foil capping, ^{148}Nd target foil, and ^{27}Al catcher foil (Al-Nd-Al) was done. The ^{27}Al foils were prepared using rolling machines and ^{148}Nd target foils were prepared by vacuum evaporation technique. The enrichment of the ^{148}Nd target used was $\approx$95.44% $\pm$ 0.1%. The thickness of the ^{27}Al capping was 10μg/cm^2, ^{148}Nd target was 100-320 μg/cm^2 and ^{27}Al catcher was 1.4-2 mg/cm^2. The detailed insights into the experimental procedure with stack foil activation can be accessed in [1].

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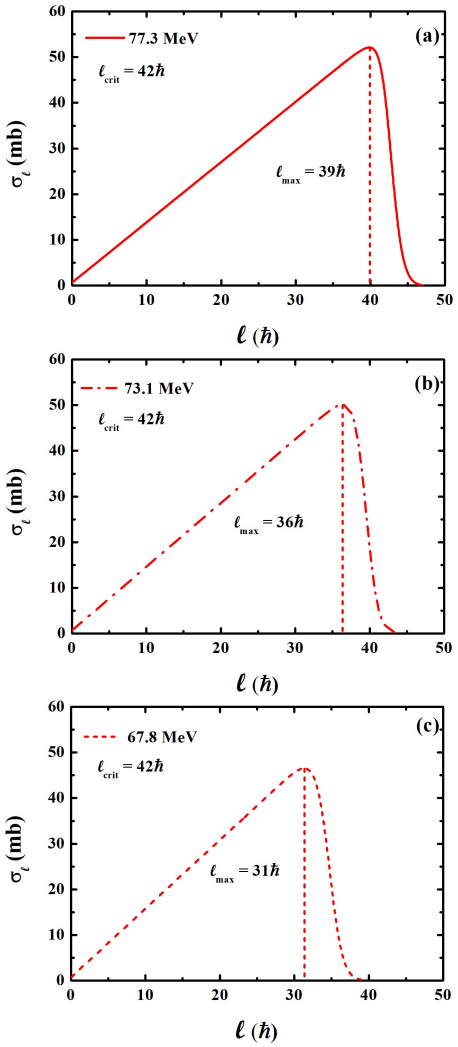

FIG. 1: Fusion ℓ distribution for ^{14}N + ^{148}Nd system calculated using the CCFULL code at various projectile energies; (a) 77.3 MeV, (b) 73.1 MeV, and (c) 67.8 MeV, and and the ℓ_{crit} for ^{14}N + ^{148}Nd system is caluclated using Sum-Rule model.

Results and Discussion

The Sum-Rule model indicates that CF probability tends to unity below ℓ_{crit}, and ICF starts contributing with CF only when $\ell \geq \ell_{crit}$. On the other hand, a couple of recent studies [1]-[2], have suggested that ICF has a noteworthy impact below ℓ_{crit}. Enhanced comprehension of the fusion ℓ distribution for the system ^{14}N + ^{148}Nd was achieved by employing the CCFULL code [6] at different energies. Figure 1 represents the fusion ℓ distribution at three different projectile energies (a) 77.3 MeV, (b) 73.1 MeV, and (c) 67.8 MeV. The ℓ_{crit} for ^{14}N + ^{148}Nd system is calculated using the Sum-Rule model [5] and is found to be 42ħ. The maximum value of angular momentum ℓ_{max} for ^{14}N + ^{148}Nd system reaches its peak at 39ħ with energies of 77.3 MeV, 36ħ at 73.1 MeV, and finally 31ħ at 67.8 MeV which is lower than the ℓ_{crit} of the system. Despite this, the Excitation Functions measurements for ^{14}N + ^{148}Nd system undeniably highlight the significant contribution of ICF at these specific energies. Therefore, the current study indicates that there are ℓ waves present below ℓ_{crit} that play a role in the ICF.

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References

[1] A. Mahato et al., Eur. Phys. J. A **56**, 131 (2020).
[2] P. K. Giri et al., Phys. Rev. C **100**, 024621 (2019).
[3] D. Singh et al. Phys. Rev. C **97**, 064610 (2018).
[4] H. Kumar et al., Phys. Rev. C **99**, 034610 (2019).
[5] J. Wilczynski et al., Nucl. Phys. A **373**, 109 (1982).
[6] K. Hagino et al., Comput. Phys. Commun. **123**, 143 (1999).