Effect of the Critical Angular Momentum on Incomplete Fusion Dynamics

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Abstract: An attempt has been made to calculate the critical angular momentum (ℓ_{crit}) from the experimentally measured total ER cross-sections and are compared with Bass model predictions (using PACE-2). A comparison between experimentally measured and theoretically calculated critical angular momentum for the systems $^{16}O + ^{45}Sc$ and $^{16}O + ^{74}Ge$ has been done. In case of $^{16}O + ^{45}Sc$ system, it is found that the experimentally measured ℓ_{crit} values are slightly lower than the theoretically calculated values at projectile energies from 66 to 114 MeV. The low values of ℓ_{crit} associated with ICF-channels for this system suggests that at these projectile energies, ICF may not be strictly associated with peripheral collision. Instead there appears to be deeper penetration of the projectile with the target at these beam energies. But for the system $^{16}O + ^{74}Ge$ at projectile energies from 65 to 112 MeV, the experimentally measured ℓ_{crit}-values are consistent with theoretically calculated values. This shows that ℓ_{crit}-values associated with ICF channels for this system suggests that at these projectile energies, ICF may be associated with peripheral collision.

1. INTRODUCTION

The study of incomplete fusion (ICF) of heavy ions with different targets has been a growing interest at energies above the Coulomb barrier [9,14]. Observations of heavy ion induced reactions show that at projectile energies above the Coulomb barrier, the dominant nuclear reaction mechanisms are

CHITKARA UNIVERSITY

Singh, D
Linda, B
Giri, PK
kumar, H
Ali, R
Ansari, A
Sathik, NPM

complete fusion (CF) and the ICF. At projectile energies just above the Coulomb barrier, both the complete fusion (CF) and incomplete fusion (ICF) are the dominant reaction mechanisms. In case of CF reaction 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 reaction 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 [2,7,8]. The first experimental evidence of ICF reactions was given by Britt and Quinton [10], 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 ≈ 10.5 MeV/A bombarding energy. Subsequently, Galin et al. [11] also observed the break-up of projectile and called such reactions, leading to the emission of "fast" alpha particles, as 'ICF reaction' or 'break-up fusion reaction'. However, major advances in the study of ICF reactions took place after the work of Inamura et al. [18] for ^{14}N + ^{159}Tb system at beam energy about ≈ 7 MeV/nucleon, wherein exclusive measurements of forward-peaked alpha-particles in coincidence with the prompt gamma-rays of the different ERs produced, were done. Semi classical theory of heavy ion (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 $\ell_{crit} < l \leq \ell_{max}$. Various dynamical models have been proposed to explain the mechanism of ICF reactions, such as Sum-rule [13], Break-up fusion (BUF) [19], Promptly emitted particle (PEP) [12] and Hot-spot [15]. However, no theoretical model is available so far to explain the gross features of experimental data available below E/A=10 MeV. Different methods have been employed for the study of ICF reactions. In the literature, there are limited studies to few projectile–target combinations. Systematic measurements are still demanded. In the present work, an attempt has been made to investigate the effect of critical angular momentum on ICF dynamics at projectile energy 4-7 MeV/nucleon. Experimentally measured total ER cross-sections for the systems ^{16}O + ^{45}Sc and ^{16}O + ^{74}Ge has been taken from the excitation functions data reported in Ref. [1,6,16]. The theoretical total cross-section has been calculated by using PACE-2 [1] for the systems ^{16}O + ^{45}Sc and ^{16}O + ^{74}Ge. Using these experimentally measured total and theoretically calculated total cross-section ER cross-sections, critical Angular momentum have been calculated for the above projectile target systems at projectile energy 4-7 MeV/nucleon.
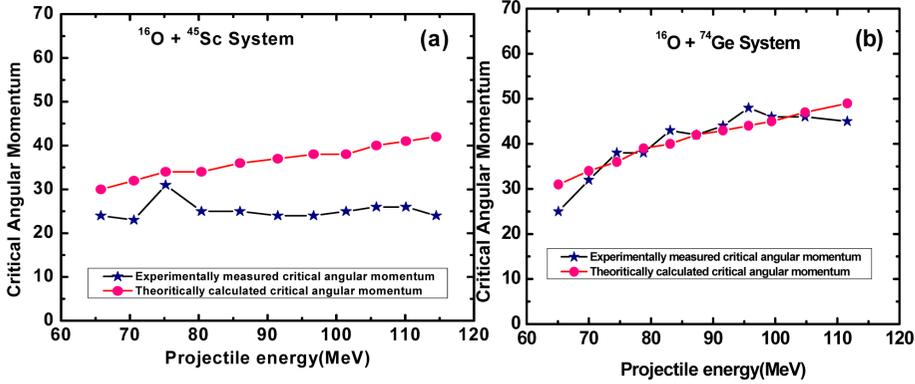
Fig. 1(a)-(b): Experimentally measured and theoretically calculated critical angular momentum for the systems $^{16}O + ^{45}Sc$ and $^{16}O + ^{74}Ge$ as function of projectile energy.

Effects of the critical angular momentum on ICF dynamics for these two systems have been discussed and presented in this paper.

2. CALCULATION OF CRITICAL ANGULAR MOMENTUM

An attempt has been made to calculate the critical angular momentum (ℓ_{crit}) from the experimentally measured total ER cross-sections and theoretically calculated total fusion cross-section from Bass model predictions (using PACE-2). The experimental and theoretical critical angular momentum (ℓ_{crit}) has been calculated by the formula given in [5]. The experimental values of critical angular momentum (ℓ_{crit}) has been calculated by using the measured excitation functions data for the systems $^{16}O + ^{45}Sc$ and $^{16}O + ^{74}Ge$ at projectile energy 4-7 MeV/nucleon [3-6]. The experimental value of critical angular momentum (ℓ_{crit}) has been calculated by taking experimentally measured total ERs cross-sections. The experimentally measured total ERs cross-section is the sum of the measured individual ERs cross-section. The theoretical values of critical angular momentum (ℓ_{crit}) has been calculated by using Bass model predictions (using PACE-2) [4]. The theoretical values of critical angular momentum (ℓ_{crit}) has been calculated by taking the total fusion cross-section of the various ERs calculated by PACE-2.

3. RESULTS AND DISCUSSION

The critical angular momentum (ℓ_{crit}) calculated from the experimentally measured total ER cross-sections are compared with critical angular momentum (ℓ_{crit}) calculated by using Bass model predictions (using PACE-2).

Singh, D
Linda, B
Giri, PK
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Comparisons between experimentally measured and theoretically calculated critical angular momentum for the systems $^{16}O + {}^{45}Sc$ and $^{16}O + {}^{74}Ge$ have been shown in Figs. 1 (a)-(b). For the $^{16}O + {}^{45}Sc$ system, it is found that the experimentally measured ℓ_{crit} -values are slightly lower than the theoretically calculated values at projectile energies from 66 to 114 MeV. The low values of ℓ_{crit} associated with ICF-channels for this system suggests that at these projectile energies, ICF may not be strictly associated with peripheral collision. Instead there appears to be deeper penetration of the projectile with the target at these beam energies. But for the system $^{16}O + {}^{74}Ge$ at projectile energies from 65 to 112 MeV, the experimentally measured ℓ_{crit} -values are consistent with theoretically calculated values. This shows that ℓ_{crit} -values associated with ICF channels for this system suggests that at these projectile energies, ICF may be associated with peripheral collision.

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