Angular momentum hindrance in mass asymmetric reactions at higher energy range

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Introduction

Heavy ion induced fusion reactions populate the compound nucleus (CN) with high excitation energy and angular momentum. If the projectile is coming with energy above 10MeV/nucleon, the fusing nuclei disintegrate before the formation of a fully equilibrated CN. However, if the energy is low formation of CN becomes a dominant process. The CN has high excitation energy, which undergoes sequential decay through fission or emission of α particles, protons, neutrons and γ rays. The states with high angular momentum decay preferentially through α-particle emission and the lower angular momentum sates decay through proton or neutron emission. Particle evaporation spectra are explained by using the statistical model assumptions to extract the information about the nuclear level density parameter and barrier penetration depth. The studies available in literature suggest that the charged particle and neutron spectra for the mass asymmetric systems satisfies the statistical model predictions, but in case of the mass symmetric systems it shows significant deviations from those predicted by statistical model calculations using the rotating liquid drop model (RLDM) moment of inertia, the transmission coefficient from the optical model for spherical nuclei, level density parameter 'a' $=A/8$ MeV^{-1} and the maximum value of angular momentum, $\ell = \ell_{max}$ [1-3]. The tail of charge particle spectra in the high energy range is softer, but in case of neutron it is harder in comparison to statistical model predictions [2,3]. So, it was observed that the charge particle and neutron spectra are not available together for the symmetric and asymmetric systems for the full energy data and the experimental spectra for symmetric systems are strongly deviated from the statistical model calculations and these calculations over predict the α-particle and proton spectra and under predict neutron spectra.

Dynamical model based code HICOL was also used to explain the anomalous deviations from the statistical model predictions, which suggests that fusion of the higher partial wave for mass symmetric entrance channel is strongly hindered and the ℓ values suggested by this model is less than classical $\ell = \ell_{max}$, calculated by statistical model based code CASCADE [5].

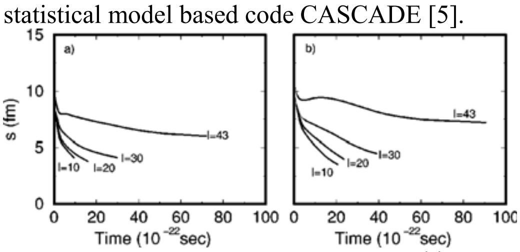

Fig. 1 Calculated evolution of the separation(s) of the colliding nuclei as a function of time for the reactions (a) $^{16}O+^{64}Zn$ at 95 MeV and (b) $^{32}S+^{48}Ti$ at 125 MeV.

But in case of asymmetric systems ℓ values suggested by HICOL code was found in good agreement with classical $\ell = \ell_{max}$, calculated by statistical model based code CASCADE.

Table1: Comparison of the angular momentum used for the two systems.

System	E_{lab} (MeV)	ℓ_{max} (CASCADE)	ℓ_{max} (HICOL)
$^{16}O+^{64}Zn\rightarrow^{80}Sr^*$	95	43ħ	43ħ
$^{32}S+^{48}Ti\rightarrow^{80}Sr^*$	125	43ħ	30ħ

In earlier studies same compound nucleus was populated at same excitation energy and angular momentum by two different entrance channels (symmetric and asymmetric entrance channels) to match the excitation energy E^* of the populated CN by fixing the projectile energy E_{lab} of the asymmetric systems [1]. No measurement is done till date in higher energy range for asymmetric system. So, it would be interesting to do the measurement of the particle evaporation spectra for asymmetric systems at higher energy range to check the consistency of asymmetric systems at higher energy range.

Theoretical Analysis

Theoretical calculation was performed using the dynamical model based code HICOL [4]. It is a well establish code, where various aspects of the dissipative heavy–ion collision are brought to centre of mass energies ranging from the coulomb barrier to several MeV per nucleon above the barrier. The dynamical evolution of the colliding nuclei is described by a sequence of shapes which basically consists of two spheres connected by a conical neck. The distance between fusing nuclei ‘s’ is plotted as a function of time for various values of ℓ in the shown figures. The dashed line corresponds to closet distance of approach (s = s_{crit}), which is taken as equal to the radius of the CN. These plots represent that the trajectories up to those $\ell > \ell_{max}$ do no approach s = s_{crit} then they do not contribute in fusion process and hence only the partial waves up to $\ell = \ell_{max}$ fuse in CN.

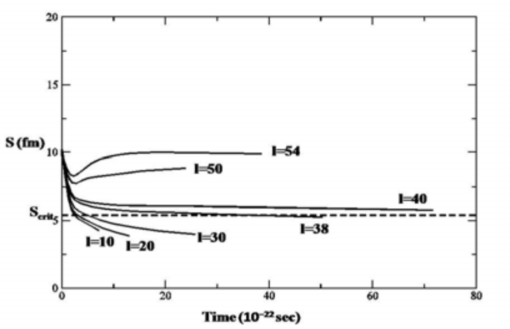

Fig. 2 Calculated evolution of the separation (s) as a function of time for reaction $^{16}O+^{64}Zn$ at 125 MeV.

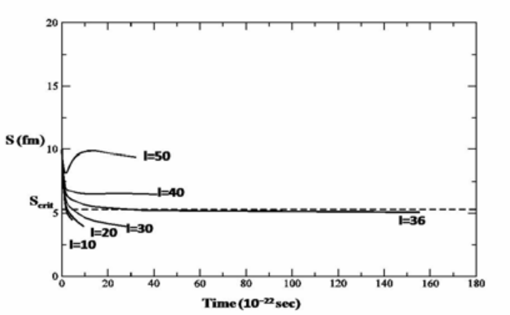

Fig. 3 Calculated evolution of the separation (s) as a function of time for reaction $^{12}C+^{64}Zn$ at 120 MeV.

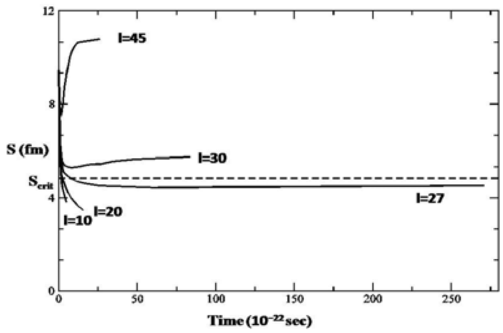

Fig. 4 Calculated evolution of the separation (s) as a function of time for the reaction $^{12}C+^{46}Ti$ at 120 MeV.

Table2: Comparison of the angular momentum calculated for three systems at higher energy.

System	E_{lab} (MeV)	ℓ max (CASCADE)	ℓ max (HICOL)
$^{16}O+^{64}Zn\rightarrow^{80}Sr^*$	125	54ħ	38ħ
$^{12}C+^{64}Zn\rightarrow^{76}Kr^*$	120	50ħ	36ħ
$^{12}C+^{46}Ti\rightarrow^{58}Ni^*$	120	45ħ	27ħ

Conclusion

The studies existing in literature suggest that the particle evaporation spectra for mass symmetric reactions shows significant deviations from the statistical model predictions while for asymmetric reactions there is no deviation. But in the present work ℓ_{max} calculated by the dynamical model code HICOL is less than the ℓ_{max} values suggested by statistical model code CASCADE for mass asymmetric reactions in higher energy range. So, it is necessary to do the measurement of particle evaporation spectra at higher energy for asymmetric system and for this work beam time request is already accepted by IUAC, New Delhi.

References

[1] J. Kaur et al., Phys. Rev. C 70, 017601 (2004).
[2] A. Kumar et al., Nucl. Phys A 798, 1- 15 (2008).
[3] M. Kaur et al., Phys. Rev. C 89, 034621 (2014).
[4] H. Feldmeier, Rep. Prog. Phys. 50, 915 (1987).
[5] F. Puhlhofer, Nucl. Phys A 280, 267 (1977).