Study of entrance channel mass-asymmetry effect on quasi-fission

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Introduction

With the availability of heavy ion beams, the study of nuclear reactions induced by heavy ions is a topic of interest for nuclear physicists cutting across the globe. Even though nuclear fission was discovered some 70 years ago all the aspects of this phenomenon, especially for the mass symmetric systems in the heavy mass region, still remains in dark. In the fusion of two nuclei near Coulomb barrier energy, any of the following two outcomes is possible for a composite system; 1) the composite di-nuclear system may evolve to form a compact mono-nuclear configuration (compound nucleus) after equilibration in energy, mass and shape degrees of freedom leading to any one of the following process. a) This excited compound nucleus (CN) may then end up as an evaporation residue (ER) after emitting neutrons, light charged particles and gamma rays. b) It reaches the unconditional mass-symmetric saddle through shape oscillations and subsequently undergoes binary fission, also called fusion – fission, if it is formed at higher excitation energy. 2) The composite system breaks up in fission like events before the formation of CN. This is known as quasi-fission (QF). Quasi-fission is a serious competitor for the formation of a compound nucleus and subsequently, the formation of an ER. Since quasi-fission occurs before the complete fusion of target and the projectile and equilibration of the CN, it hinders the formation of the ER[1]. ER are unambiguous signatures of CN formation and it is reported that the experimental fusion cross sections in the mass~200 region is significantly reduced even for very asymmetric reactions [2], due to the onset of non compound nuclear process such as QF. It has been suggested [3] that, for a nuclear reaction, if $Z_P Z_T > 1600$ (where Z_P = mass of the projectile and Z_T = mass of the target) then it leads to quasi-fission. However, recently it has been established that the onset of QF starts as early as $Z_P Z_T \sim 1000$ [4].

Present Study

When two different nuclear reaction channels forming same CN are compared, QF is manifested with a strong suppression of ER production for the more symmetric system[5]. The present work compares two nuclear reaction systems leading to same CN ^{188}Pt *viz.,* ^{19}F + ^{169}Tm and ^{64}Ni+ ^{124}Sn, and the QF contributions are estimated for both the cases. Data due to R.J.Charity et al[6] and W.S.Freeman et al[7] are used for calculation. Here the $Z_P Z_T$ value for the most asymmetric system, ^{19}F + ^{169}Tm, is found to be 621 and that for the symmetric system ^{64}Ni+ ^{124}Sn is found to be 1400. Theoretical calculations have been performed using statistical code PACE4.

Analysis

Measured and calculated evaporation residue cross section for each reaction is plotted, for the excitation energy range ~35-80 MeV in figure1 and 2 respectively.

It is seen that for system ^{64}Ni+ ^{124}Sn of W.S.Freeman et al, the experimental data is found to be largely deviating from statistical calculations above the coulomb barrier. This could be due to the onset of QF.

In the case of ^{19}F + ^{169}Tm of R.J.Charity et al, which is more asymmetric and $Z_P Z_T < 1000$ predicts the experimental cross section satisfactorily.

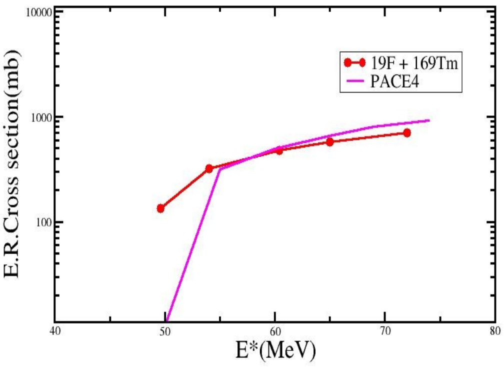

Figure 1 Comparison between experimental and PACE4 statistical calculations for the reaction

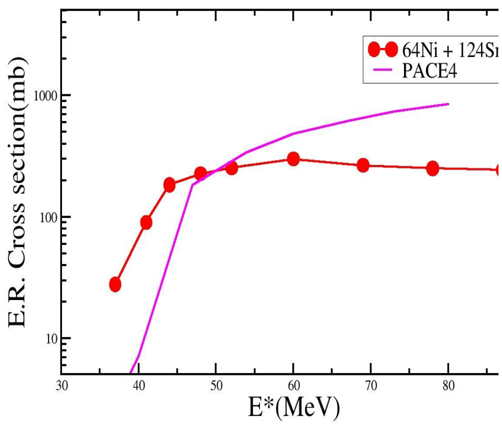

Figure 2: Comparison between experimental and PACE4 statistical calculations for the

A comparative study between the experimental values of the two systems is plotted in figure3.

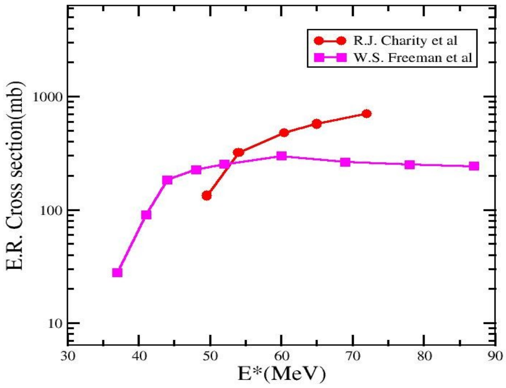

Figure 3: The cross section for the comparatively more symmetric system ^{64}Ni+ ^{124}Sn shows a dip when compared with the cross section of more asymmetric system ^{19}F + ^{169}Tm.

The above figure also shows a decreased ER cross section for the more symmetric system. This may me due to the strong Coulomb repulsion between the reaction partners compelling them to re separate before achieving an equilibrated state. It is also inferred that the lower cross sections of the ER of the symmetric system can be connected to complete fusion stages.

Conclusion

Entrance channel effects play an important role in the reaction dynamics of heavy ion systems. A decrease in the entrance channel mass asymmetry results in QF. Further the QF contributions seems to be increasing with excitation energy for heavy mass system.

References

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