A Study of Fusion-Fission and Quasi-Fission processes in ^{35}Cl + ^{184}W and ^{37}Cl + ^{182}W systems

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The study of fission in heavy ion interactions has been a topic of resurgent interest [1]. The measured charge and mass distributions are important post fission observables and provide testing grounds for theories of nuclear fission. An important observation in the earlier studies on fission reaction dynamics was the observation of asymmetric mass distributions at lower excitation energies in majority of actinides and decrease of asymmetry with the increase in the excitation energy. This behavior of mass distributions was explained when shell corrections to the liquid drop model fission barriers [1] were incorporated. It may be pointed out that with the increase in excitation energy (*E**), asymmetry in the mass distribution was found to decrease, because of the gradual washing off of shell effects. At relatively higher excitation energies symmetric mass distributions are observed. Though, combination of the shell effects and the liquid drop model can explain the basic features of nuclear fission [2], there are certain aspects that are far from being completely understood and nuclear fission continues to be an important area of investigation [3]. Studies on the effect of excitation energy and angular momentum on various fission observables have provided deeper insights into the mechanism of fission. In recent studies, heavy ions (HI) have been increasingly used as projectiles to study the fission of compound nuclei (CN) for a wide range of fissionability parameter (Z^2/A), excitation energy, and angular momentum.

In general, some of the dominant reaction processes in heavy-ion interactions are; (i) complete fusion (CF), (ii) incomplete fusion (ICF), (iii) fission of excited composite nucleus, (iv) quasi-fission etc. The details on CF and ICF can be found elsewhere [4]. In a qualitative way the process of heavy ion interactions may be broadly categorized into three stages. In the first stage the colliding nuclei overcome the Coulomb barrier of interacting partners and approach the point of contact and may lead to the quasi-elastic and deep-inelastic channels giving rise to projectile-like and target-like fragments. Here, the interacting partners may evolve into somewhat spherical composite system as a single entity and after the dynamic deformation and exchange of several nucleons, the two interacting heavy nuclei may re-separate into projectile-like and target-like nuclei or may undergo fission without formation of statistically equilibrated CN, referred to as quasi-fission. In the next stage the excited CN undergoes statistical equilibrium followed by emission of neutrons and γ-rays decreasing its excitation energy leading to the formation of residual nucleus. The composite system so formed may also lead to fission depending on the excitation energy and angular momentum involved. This is referred to as fusion- fission process. As such, the quasi-fission and the fusion-fission are the entirely different modes of reaction processes involving different reaction time scales, as well, and compete with each other. A proper choice of` projectile-target combination along with excitation energy is required to study these competing processes. Some of the important features, that are generally used to study these processes, are the study of fission fragment mass distribution as well as pre and post-scission neutron multiplicities i.e. M_{pre} & M_{post} respectively. The cross section data of fission products are also gaining importance for the production of specific radioactive ion beams.

In order to explore the dynamics of the fusion-fission and quasi-fission processes, we plan to undertake a program to measure the mass distributions and neutron multiplicities for large number of projectile-target pairs at different excitation energies. Pre-measurement analysis of two systems ^{35}Cl +^{184}W and ^{37}Cl + ^{182}W, is presented in the present work. In these two cases the same compound nucleus $^{219}Pa^*$ is formed. The neutron multiplicity measurements may be used as a tool to disentangle the quasi-fission and fusion-fission processes and may give information about the projectile dependence of these processes. The Businaro–Gallone (BG) point α_{BG} has been calculated for $^{219}Pa^*(Z^2/A=37.8)$ and is found to be 0.8783. The α_{BG} point can be used to explore the behavior of the saddle point and its stability against mass asymmetry. In the present work, the fission fragment mass distribution, charge distribution, M_{pre} & M_{post} for both the systems have been calculated using the code NRV [5]. As a representative case, in Fig. 1, the fission fragment mass distributions for the system ^{35}Cl + ^{184}W, calculated at widely different excitation energies from 50-200 MeV are shown. As can be seen from the figure, the calculated mass distributions are found to be symmetric as expected from the Bussinaro Gallone mass asymmetry concept i.e. α (~ 0.68) < α_{BG}. The centroid, width and the variance of mass distribution at different excitation energies are tabulated in Table 1, for ^{35}Cl + ^{184}W system. Further, with the increase in energy the width and variance of mass distributions are found to increase systematically.

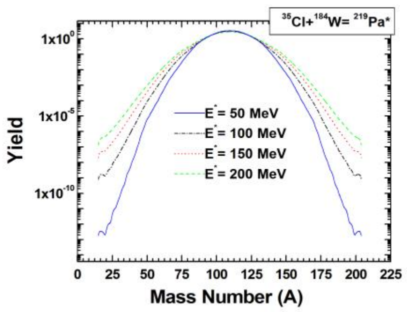

Fig.1 Typical calculated fission fragment mass distribution at four different excitation energies.

Similar observations have been found for the charge distributions as well, for both the systems. In Fig. 2, the pre and post scission neutron multiplicities, calculated as discussed above are shown. As can be seen from the figure, the post-scission neutron multiplicities (M_{post}) are relatively higher than pre-scission neutron multiplicities (M_{pre}), at lower excitation energies

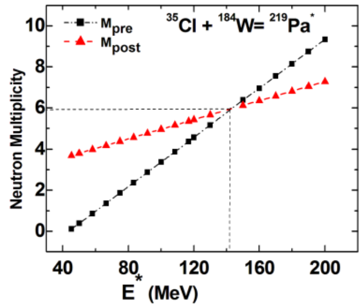

Fig. 2 Calculated pre-scission and post-scission neutron multiplicities as a function of excitation energy as discussed in the text.

Table 1: The empirical parameters of the mass distribution obtained from NRV calculations.

E^* (MeV)	Centroid	Width	Variance
50	109.5	6.83	11.65
100	109.5	6.91	11.93
150	109.5	7.17	12.84
200	109.5	7.41	13.72

as expected. However, with increase in energy the post scission neutron multiplicities are found to decrease as compared to pre-scission neutron multiplicities, indicating the probability of quasi-fission at relatively higher energies and follow almost a linear behavior with energy. Detailed calculations for the proposed experiments will give information about the fission reaction dynamics and will be presented.

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