Mass distribution as a probe to study the dynamics of Nuclear Fission

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The work presents investigations on the angular and mass distribution of fission fragments on heavy ion induced fission reactions. For the last few years, the focus on the research in this field was on the formation of compound nucleus close and below the Coulomb barrier, as such studies have a direct bearing on the synthesis of super heavy nuclei. Since the principal decay mode of the super heavy nuclei would be fission reaction, the studies of the competition between the fusion and fission and the factors hindering the yields of super heavy elements are intensely followed.

The present investigations were carried out to measure precisely the distribution of fragment mass in the same reactions, which showed departure from production of an equilibrated compound nucleus. We have used a double arm time-of flight spectrometer with a long flight path to measure the precise masses of complementary fission fragments. Necessary large area position sensitive gas detectors, the method of experiments and data analysis were developed [1] . The experiments were mostly done using pulsed heavy ions from the 15UD pelletron at the Nuclear Science Centre, New Delhi.

The first strings of measurements [2] were for a spherical target, ^{209}Bi, with oxygen and fluorine projectiles. The angular distribution measurements in the same experiments supplemented the existing angular anisotropy measurements to establish beyond doubt the systems scrupulously followed the predictions based on the macroscopic theories of the production of equilibrated compound nucleus. The mass distributions were symmetric around the average of the target and projectile mass, and the width of mass distribution varied smoothly with the beam energy, fully conforming to a statistical binary split of the compound nucleus.

The next series of experiments [3,4] were done using a deformed target of ^{232}Th and projectiles of carbon, oxygen and fluorine. The angular anisotropy data existing in these systems showed an anomalous increase of the anisotropy as the beam energy decreased through the Coulomb barrier. The mass distributions were measured for these systems. In case of all the systems with deformed target, at all energies, the mass distributions were symmetric, peaked around the average of the target and projectile masses, as in the case of systems with spherical target, viz,^{209}Bi. However, the width of the mass distribution, σ_m^2, showed completely anomalous behaviour. For ^{19}F + ^{232}Th, the σ_m^2 decreased monotonically as the energy is decreased, but near the Coulomb barrier, value of σ_m^2 started to rise and reached a value which is more than 150 $\%$ of the extrapolated value at that energy. Thereafter, σ_m^2 value again started to decrease. Exactly similar trend of the σ_m^2 values were observed for oxygen and carbon projectile, although the sharp increase of σ_m^2 values progressively got smaller for oxygen and carbon projectiles.

The close similarity of the trends of the fragment angular anisotropy and the width of mass distributions immediately suggested a common explanation of the observed anomalous rise in both the observable for deformed target and the same energy regions. In orientation dependent quasi-fission formalism, it has been postulated that due to microscopic effects of the relative elongated configuration of the projectile fusion with the deformed target through the polar region, the fusion barriers are lowered and simultaneously, the system prefers to reach directly a saddle shape (which may be mass asymmetric) in a quasi-fission reaction, in contrast to the initial compact configuration leading preferentially to a formation of compound nucleus when the projectile hits the equatorial region of the deformed target. Hence, it was conjectured that up to a critical angle on the relative orientation of the symmetry axis of target with respect to the projectile trajectory, normal compound nuclear fission and the quasi fission mechanisms can be mixed. With cross section weighted admixture of the two fission modes, the observed anomalous rise in σ_m^2 could be phenomenologically explained for all the systems [4].

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