Shell effects in fission fragment mass distribution of neutron deficient nuclei around A∼200

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Nuclear fission is the most drastic decay mode of a nucleus to attain stability. This complex process results in splitting of a single nucleus into two or more heavy nuclei of comparable masses, releasing large amount of energy. A detailed understanding of fission mechanism is crucial for the fundamental research like nuclear physics and astrophysics and its applications in nuclear energy, production of isotopes for medical and industrial purposes and safeguards. Although nuclear fission is a large scale collective phenomena, this process is primarily governed by a delicate interplay of the macroscopic and the microscopic (single particle) effects, whose accurate modelling is still a challenge for nuclear theory. In this scenario, experimental determination of different observable quantities associated with this process, for example final fragment masses, their total kinetic energies, angular distribution etc. are of fundamental importance for nuclear physics. Among these observables, fission fragment mass distribution is an efficient tool to probe structure effects and dynamics associated with the process[1].

In the recent times, an unexpected observations of mass-asymmetric fission in ^{180}Hg and multimodal fission in ^{194,196}Po, ^{202}Rn, populated just above the fission barrier opened an unexplored region of a "new type of asymmetric fission" and gave the opportunity to test the knowledge gained in the actinide region. Different theoretical models proposed to explain the result gave different interpretations. The fully self-consistent models correlate the observed mass asymmetries to the shell structure of pre-scission configurations and associated it with molecular structures. Scission point model, which strive to explain the result assuming that statistical equilibrium is established at scission, could also explain the results. A recent time dependent microscopic study, showing the impact of pear-shaped fission fragments in the mass-asymmetric fission in actinides, also speculate the importance of octupole deformation of the fragments in fission. In order to test the validity of these different theoretical models, more fission data is an urgent requirement in sub-lead region. Hence, to get a detailed understanding of role of shell effects in deciding fission fragment mass distribution around A∼200, we performed three imperative investigations in the present thesis work that is, (i) disentangling the role of entrance channel dynamics versus shell effects in deciding fragment mass split, (ii) examine evolution of different modes of fission with compound nucleus N/Z and (iii) a consistent analysis of low-energy fission fragment mass distribution data collected so far to get a unified picture of fission process. A brief description of all these studies is as follows,

In our measurement of fragment mass distribution in fission of ^{191}Au[2], formed via two very different entrance channels, ^{16}O+^{175}Lu and ^{37}Cl+^{154}Sm with E^*_{CN} ∼39-50 MeV and 46-64 MeV respectively, we observed significantly (∼30%) broader mass distribution in

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case of ^{37}Cl+^{154}Sm system than those for ^{16}O+^{175}Lu at similar E^*_{CN} and $\langle \ell \rangle$. Failure of statistical relation, semi-empirical code GEF as well as the 4D Langevin dynamical model in explaining this enhanced width of the observed mass distribution in case of heavier projectile gave us conclusive evidence of substantial presence of quasifission for the more symmetric entrance channel. The Dinuclear system (DNS) model prediction of 22% quasifission in case of ^{37}Cl+^{154}Sm system was also found to be in good agreement with the experimental observation. Also, a systematic analysis of the available experimental data demonstrated significant presence of quasifission whenever heavier projectiles (Z≥17) were used with spherical or deformed targets to investigate fission of neutron deficient sub-Pb nuclei. These observations gave us a clear indication that not only the shell effects, but the dynamics in the entrance channel also have a significant role in influencing the fission of nuclei around A∼200. Hence, along with shell effects, the quasifission aspects are also needs to be necessarily considered for interpreting the heavy-ion data unambiguously. This work illustrates that for systems involving heavy projectiles (Z≥17), quasifission contribution should be taken care correctly while studying asymmetric CN fission in the mass region A∼200.

By measuring fragment mass and total kinetic energy properties for fission of ^{198}Po[3] produced via ^{28}Si+^{170}Yb reaction with E^*_{CN} = 34.5, 37.0 and 44.1 MeV, we investigated the presence of multimodal fission along Po chain. In the analysis of this measurement we inferred the presence of asymmetric partitions by observing a weak flattening of TKE with mass, and the non-monotonic evolution of the fragment-mass distribution width with excitation energy. Considering the good description achieved by the GEF code for different measurements in the pre-actinide region as well as for our measurement of ^{198}Po with $E^*_{B_f}$=15.7 MeV, we did GEF calculation to trace back the fission properties of ^{198}Po close to fission barrier. The so obtained mass distribution is triple humped and contributes in establishing the gradual evolution along the polonium chain.

In a systematic analysis of the experimental information on fission of neutron-deficient nuclei in sub-lead region, we observed that the leading role in deciding fragment mass distribution is primarily played by the light fragment proton number $Z_L \approx 36$[4]. This result is in contrast with previous predictions where neutron shells were considered to be dominant for theoretical modelling of fission in pre-actinide region. Combined with the previously established leading effects in the actinide region, we can conclusively say that in general its the fragment *proton* shell that is primarily responsible for asymmetric fission. In the actinide region its proton shell of the heavier fragment while in pre-actinide nuclei its proton shell of the lighter fragment that is basically responsible for asymmetric mass split. Present thesis work give a crucial input and a new direction for theoretical modelling of the fission process where until now neutron shells are observed to play dominant role in deciding fragment mass split. The basic physics mechanism behind this newly observed phenomenon of dominant proton shells over neutron is yet to be investigated completely.

References

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