Origin of asymmetry in low energy fission of preactinides

K. Mahata[1,2]*
[1]Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA and
[2]Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, INDIA

Observation of asymmetric fission in the preactinide region at low energy provides an opportunity to improve our understanding of the fission process. Several experiments have been carried out to study the role of N/Z, entrance channel and excitation energy. In contrast to the heavy fragment charge driven asymmetry in the actinide region, evidence of stabilization in light fragment proton configuration have been observed in the experimental data. Different theoretical models proposed different mechanisms to explain the observed asymmetric fission in this region. Discrepancies have also been observed between the experimental results and theoretical predictions. Further investigation is required for quantitative understanding of asymmetric fission in general and preactindes in particular.

Interpretation of the complex process of nuclear fission continues to be a challenging task. Strongly favoured asymmetric mass fragments in fission of actinides is explained by invoking microscopic corrections to the liquid drop potential energy surface. As the mass number of the fissioning nuclei decreases below A $\approx$ 224, a transition from asymmetric dominated to symmetric dominated fission was observed in electromagnetic induced fission, indicating the weakening of shell effects [1]. Further presence of shell effects was evident from the appearance of a dip at the middle of the fragment mass distribution for ^{201}Tl and flat top distributions in nuclei around it from the studies using p and α beams on preactinide targets [2]. For the lighter preactinides, the measured mass distributions were found to be single peaked, indicating the dominance of liquid drop in that region. Recent observation of almost exclusively asymmetric mass distribution outside the actinide region in β-delayed fission of neutron deficient ^{180}Hg [3] has given a new impetuous for studying fission in the preactinde region both experimentally and theoretically.

In β-delayed fission, the fissioning nucleus is populated just above the fission barrier, thus it can sense the full shell correction. However, there are not many cases where β-delayed fission can occur. Only a few systems have been studied so far and in most of the cases the statistics is very poor due to extremely low cross-section, hindering definite conclusion. The charged particles induce fusion-fission reactions have also been exploited to study the fission properties in this mass region. Such studies are mostly limited to excitation energies $\approx$ 20 MeV above the saddle point due to the entrance channel Coulomb barrier. Though the shell corrections fade-out significantly at these energies, fusion-fission studies have been found to be sensitive to it [4]. Population of the neutron deficient preactinide region requires heavier beams (Z$\geq$17). Heavier beams also bring in large angular momentum and open up the possibility of fission before complete equilibration (quasi-fission). Presence of such a process also results in asymmetric mass distribution and needs to be considered for unambiguous interpretation of the data [5]. Recent results from charged particle induced fission reactions will be discussed.

Several measurements have been carried out recently using proton to iron as one of the colliding partners to measure fission fragment mass distributions in the preactinide region. Fragment mass as well as total kinetic energy (TKE) have been estimated from the measurement of time-of-flight and emission angles of the fragments. The experimental mass dis-

*Electronic address: kmahata@barc.gov.in

tributions in many cases show a dip at the middle or flat top. Multi-Gaussian fit are employed to extract the mean positions, widths and fraction of the asymmetric components from the experimental mass distributions. Information about the charge distributions were extracted under the assumption of unchanged charge density (UCD) in most of the studies.

In a systematic analysis of the available experimental data, it was observed that the mean Z value of light fragment remains constant at Z $\approx$ 36, while the mean Z value of heavy fragment peak increases with increasing Z of the fissioning nuclei [4]. No such preference was observed in neutron sharing between the fragments. Mean neutron numbers of both light and heavy fragments were found to increase monotonously with increasing neutron number of the fissioning nuclei. Thus it was evident that the asymmetric fission of preactinide nuclei is driven by the stabilization of the light fragments at Z $\approx$ 36. When combined with the existing results in the actinide region, a striking connection emerged, showing the change over of stabilizing role from light fragment in preactinides to heavy fragments in actinides. Role of Z $\approx$ 45 shell was also inferred in some experimental studies.

Several theoretical models have been employed to understand the observed asymmetric fission in the preactinide region. The Brownian shape motion (BSM) approach on a 5 dimensional potential energy landscape has been used to calculate mass distributions for a large number of nuclei in this mass region and predicted a large island of asymmetry. The calculation of the single-particle levels of ^{186}Pt, which is at the center of the BSM predicted island of asymmetry, showed a large gap at the neutron Fermi surface for asymmetric shape, favouring asymmetric saddle shapes. However, the experimental mass distributions for ^{187}Ir, which is also located very close to the center of the BSM predicted island of asymmetry, are found to be symmetric [6]. Though the initial results using the microscopic energy density functional (EDF) model highlighted the contribution of neutron shells in the nascent fragments, the dominance of proton configuration over that of neutron was observed when the calculations were performed for more systems. Several other theoretical works highlighted the role of prescission configuration in asymmetric fission. The experimental mass distributions could be reproduced well using the semi-empirical code general description of fission observables (GEF), which incorporates a new fission mode at Z $\approx$ 36.

Possible presence of quasifission in the same region was investigated by populating the same compound nuclei(^{191}Au) via two different entrance channels, namely ^{16}O+^{175}Lu and ^{37}Cl+^{154}Sm. It was observed that the measured mass distributions for the Cl induced reaction was much broader than those for the O induced reaction at similar excitation energy and angular momentum [5]. The observed difference in the mass distributions between the two entrance channels could be explained using a di-nuclear system model. Competing presence of quasi-fission and asymmetric fusion-fission was observed in this region in reactions involving projectiles with Z $\geq$ 17 from a systematic comparison of the available experimental mass widths.

In summary, even though lots of experimental as well as theoretical studies have been performed to investigate the origin of asymmetric fission in the preactinide region at low energy recently, quantitative understanding remains elusive. This talk will highlight the important advances in this topic.

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