Ternary fission studies of heavy and superheavy nuclei

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Though, seventy five years have passed since the discovery of fission, the fission physics still offers new challenges and problems which are yet to be explored and understood. Hahn and Strassman first reported about the division of heavy radioactive nucleus into two by the bombardment of neutrons. Later, Peterzhak and Flerov reported the spontaneous breakup of the heavy radioactive nucleus into two. Simultaneous advancement made by Bohr on the theoretical aspects helped to understand the fission mechanism based on the simple liquid drop picture. The liquid drop theory very well accounted for the energy released in a binary fission process and further indicated that the division of a heavy radioactive nucleus into more than two fragments would release more energy than binary fission.

Alvarez first reported the breakup of a heavy radioactive nucleus into three fragments. Since then several studies were made to understand the dynamics, energetics about the ternary fission process. Earlier experimental studies were based on the intensity and range of the tracks recorded, which helped to understand the ternary fission process. Later advancements helped to study the angular, energy and momentum distributions of the ternary fission process. Earlier experimental studies revealed ^{4}He as the mostly observed third fragment along with the main fission fragments in a direction perpendicular to the main fission fragments path.

Recently, interest has been mounted theoretically and experimentally to search for heavier third particle accompanied ternary fission events. Hence, a systematic study in heavy and superheavy elements is very much warranted to explore the possibility of ternary fission with higher ternary to binary ratio.

In this thesis, the recently proposed three cluster model [1] has been used to study the ternary fission process in heavy and superheavy elements region. Angular dependence in the ternary fragmentation potential is attempted for the first time [2]. Various ternary breakups, including the true ternary breakup configurations of heavy [3] and superheavy elements [4] are searched by minimizing the ternary fragmentation potential energy surfaces (PES) for all possible combinations with three different arrangements. Also, studies are made for the kinetic energy distribution of the ternary fragments [5].

In the so far identified ternary fission events the third fragment is always found to emit in a direction perpendicular to the main fission fragments. Further, in the spontaneous ternary fission process the heaviest third fragment reported is ^{14}C and the third fragment as heavy as Ca is reported in the induced ternary fission process. Recently, theoretically the competition between a triangular and collinear configuration of three fragments through PES is studied. In this thesis, a detailed study describing the competition between collinear and triangular geometry by analysing the angular dependence of the ternary fragmentation potential energy surfaces of ^{252}Cf is presented. The PES are calculated for all possible ternary breakups starting from a collinear configuration leading to a triangular configuration where all the three fragments surfaces touch each other referring to the touching configuration. For angles beyond the touching configuration, the fragments start to overlap. Further, the role of positioning of the three fragments corresponding to three different arrangements is also analysed for two different angular mo-

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mentum values. It is found that, the angular momentum does not influence the potential strongly. The results show a clear preference for collinear configuration with heavy third fragment positioned in the middle over triangular configuration. The study has been extended for all possible third fragments in a collinear configuration.

Further, the study about the possibilities of various collinear cluster tripartition (CCT) modes including the true ternary fission modes of various transactinides from U to Fm within TCM is presented. For this study, all possible combinations are minimized by an algorithm put forth for the first time called as two dimensional minimization with respect to the charge numbers Z_1, Z_2, and Z_3 of the ternary fission fragments. The PES and the Q-values for the minimized combinations corresponding to three different arrangements for the various parent nuclei considered are presented in a ternary plot indicating all the three charges (or masses). From the ternary plot, a strong minimum in the PES and maximum in the Q-values are seen for the true ternary fission region. Further, it is seen that with the increase in the charge number of the parent nucleus considered, the true ternary mode region is found to enhance. Particularly for an arrangement in which the fragments are kept collinearly from heaviest to lightest, true ternary modes are found to have a deeper minimum in PES competing with the heavy third fragments (around $A_3 = 40$ to 50) accompanied CCT modes. Also, the results indicate several strong CCT modes for the arrangement in which the lightest fragment is kept at the middle.

Superheavy elements due to shell stabilization has a strong preference for disintegration by alpha emission than fission as expected within the liquid drop picture. However, there has been recent theoretical interest to look for heavy cluster emission as well as the possibility of ternary breakups in superheavy region. In this thesis, ternary fission studies of superheavy elements are also presented. For this study, three parent nuclei have been chosen such that their charge numbers $Z = 114$, 120 and 126 and keeping the neutron number of these three parent nuclei as $N = 184$ resulting in the mass numbers of parent nuclei as $A = 298$, 304 and 310 respectively. The two dimensional minimization process is employed to study the PES in three different arrangements. The results indicate that several light mass nuclei have very low fragmentation potential energy of similar order for an arrangement in which the lightest fragment is considered at the center indicating the larger possibility to look for several light mass fragment accompanied ternary breakups. Further, from the results it is seen that of the different parent nuclei considered, the cluster region is found to increase with an increase in the mass number of the parent nucleus.

Kinetic energy distributions of cluster fragments in the ternary fission of ^{252}Cf are studied. For this study, the charge numbers of the three fission fragments are fixed as 50, 28 and 20. All possible mass combinations for these charges are identified from the experimental mass tables. The fragmentation PES and Q-values for all possible channels are calculated. The kinetic energy distributions of all these ternary channels are also calculated within a two step approach. Further the role of excitation energy of the intermediate fragment on the kinetic energies of the fission fragments is also discussed.

References

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