True ternary fission in $^{310}_{126}$X

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Introduction

Superheavy nuclides are those whose charge number is beyond the heaviest long living nuclei that have almost negligible liquid drop fission barrier but their stabilization is only because of the shell effect. The half-life of superheavy elements is decreasing with the increase in the charge numbers. From this tendency, it can be assumed that there will be a natural limit on the production of new superheavy nuclides. However, the shell effect property in the nucleus can considerably enhance the stability of the superheavy nuclide. Hence, the shell effects and fission potential barrier are found to be the important factors in the stability of the superheavy nucleus.

In 1939, Bohr and Wheeler predicted that other than α - decay, spontaneous fission is the predominant decay mode in the heavy and superheavy nuclides. During the fission of a nucleus, it can split up into two, three or more. In the case of superheavy nuclide, splitting into three (i.e., ternary fission) may be a dominant mode to look for, in future experiments. The reason is that the fission fragments are always try to be close to closed shell structure, hence, it is energetically possible to form two tin like isotopes accompanied with light fragments for example $^{132}_{50}$Sn + $^{132}_{50}$Sn + $^{34}_{14}$Si in the ternary fission of $^{298}_{114}$X [1]. It is reported that the yield of ternary fission relative to binary fission is much higher in superheavy nuclei than that in the actinide region [2].

Three cluster model

Ternary fission is the process of splitting of a nucleus into three nuclei either spontaneously or in induced reaction. Since, the ternary fission has a lot of possible combinations (phase space), it is not easy to minimize the energy for ternary fission similar to that of binary fission. Recently, "Three Cluster Model" has been proposed to explain the ternary fission of radioactive nuclei. The advantage of this model is that it is possible to minimize the ternary fragmentation potential energy with respect to mass and charge asymmetries. The probable ternary fragment combinations can be identified through the proper charge minimization process. The minimization procedures are explained in Ref. [3].

The ternary fragmentation potential between the three fragments is defined as,

$$V_{tot} = \sum_{i=1}^{3} m_x^i + \sum_{i=1}^{3}\sum_{j>i}^{3}(V_{Cij} + V_{Nij}) \quad (1)$$

where, m_x^i are the mass excesses of the three fragments. V_{Cij} and V_{Nij} are Coulomb potential and attractive nuclear potential.

Results

We present in Fig. 1 the ternary plots of the potential energies as a function of neutron numbers as well as proton numbers corresponding to the parent nucleus $^{310}_{126}$X for a collinear arrangement in which the lightest fragment kept at the end. The magic numbers are denoted by dashed pink color lines to see the importance of closed shell effects in the ternary fragmentation.

In Fig. 1, the ternary combination corresponding to the deep minimum is $^{136}_{54}$Xe + $^{88}_{36}$Kr + $^{86}_{36}$Kr which is in the true ternary fission region. The Q - value is always found to be maximum in this region. This suggests that the true ternary fission mode is the most preferable mode than any other modes in superheavy nuclei. Though, α - decay is dominant decay mode for superheavy region, α - accompanied ternary fission seems to be a non-favorable breakup since there is no strong

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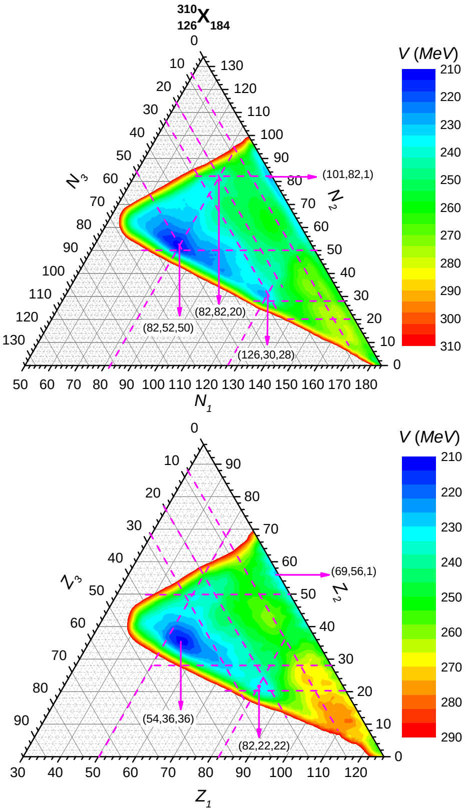

FIG. 1: (Color online) Potential energy surfaces of neutron minimized (upper) and proton minimized (lower) ternary fission fragments in the fission of $^{310}_{126}$X for an arrangement in which the lightest fragment kept at the end.

minimum and high Q - value in the light mass region.

In Ref. [4], it is seen that the ternary fission of heavy nuclei has minimum potential energy in the true ternary fission region as well as in a region with $Z_3 = 2$. But there is a deep minimum in the potential energy surface in the region of $Z_3 = 2$. However, for superheavy nucleus considered in this study, the deep minimum is seen in the true ternary fission region alone. No other stronger minimums are seen in light mass region.

In addition to the minimum in the true ternary fission region, there is a minimum around the neutron numbers $N_1 = 126$, $N_2 = 30$ and $N_3 = 28$ (in neutron minimization) and proton numbers $Z_1 = 82$, $Z_2 = 22$ and $Z_3 = 22$ (in proton minimization) which correspond to the ternary combination $^{208}_{82}$Pb + $^{52}_{22}$Ti + $^{50}_{22}$Ti. Further, there is a region of minimum along $N_1 = 82$ (in neutron minimization) and $Z_1 = 50$ (in proton minimization) in the ternary fission of the nucleus considered. This suggests that the probability of observing $^{132}_{50}$Sn as one of the fission fragments is more.

Some of the fragments in the proton minimized combination do not exactly match with proton magic numbers. However, the most of the fragments in the neutron minimized combinations are exactly match with neutron magic numbers. This result explains the fact that the fragments with neutron magic numbers are the dominant one in ternary fission of superheavy nuclei. Similarly, fragments with proton magic numbers are dominant one in the ternary fission of heavy nuclei [4].

Summary

All possible combinations are minimized by the two dimensional minimization process and minimized with respect to neutron numbers and proton numbers of the fragments. Potential energy is low and Q - value is high at true ternary fission region. It shows that true ternary mode is the dominant mode in the ternary fission of superheavy nuclei. Also, the results show that the fragments with neutron magic numbers are the dominant one in the ternary fission of superheavy nuclei whereas the fragments with proton magic numbers are the dominant one in the ternary fission of heavy nuclei.

References

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