Influence of the nuclear driving potential on the quasi-fission phenomenon

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Last few decades have witnessed a great success in synthesizing super heavy elements (SHEs) with Z=112-118 expected as evaporation residue (ER) of the compound nucleus (CN) formed through hot fusion reaction on actinide targets. These experimental ventures have confirmed the existence of island of stability near shell closure of Z=114, 120, 122 and N= 184. However, the fusion process of heavy ions ($A \geq 27$) on massive targets is different from that induced by light ion wherein fusion occurs immediately after capture of the projectile. The composite dinuclear system formed after capture of two incident massive nuclei decays to highly asymmetric mass fragments via quasi-fission (QF) before it reaches a compact shape near the equilibrium ground state. QF reduces the probability of compound nucleus formation acting as an inevitable hindrance to ER formation.

The reported values of the cross section for SHE synthesis is few femto barns therefore it is necessary to know in advance the favorable conditions for the formation of SHE. Few of the primary conditions are stability of CN against fission, choice of projectile-target combination and optimum energy range. This requires a comprehensive study and understanding of the hindrances namely QF involved in SHE synthesis .

QF is a faster process (few 10^{-21} s) than CNF and its experimental signatures differ from those of fusion-fission i.e large angular anisotropy, large variance in mass distribution, asymmetric mass angle correlation, lower particle multiplicities and higher total kinetic energy of fragments. Different factors influencing the QF probability are relative orientation of interacting nuclei, entrance channel coulomb factor, excitation energy, angular momentum, entrance channel mass asymmetry and the shell structure in the entrance channel and the compound nucleus.

The current calculation focuses on the study of the influence of shell structure and the phenomena of mass drift on the the nuclear driving potential and its correlation with fission fragment mass distribution. For this purpose potential energy at scission point as a function of atomic number has been calculated with NRV [1] code using proximity model and displayed alongside with the mass distribution. FIG 1 presents a systematic study of varied systems with increasing entrance channel mass asymmetry and decreasing coulomb factor. It is observed that with increasing entrance channel mass asymmetry the driving potential minima shifts towards the symmetric mass from 216u of ^{64}Ni+^{238}U to 185u of ^{26}Mg+^{248}Cm supporting the thesis of mass drift that is experimentally observed in systems undergoing QF. Moreover, asymmetric QF is a manifestation of nuclear shells in the composite system and the concurrent study of the driving potential univocally directs to the presence of Z = 82, N = 126 in the heavy fragment and Z = 28, N = 50 in the lighter fragment of the experimental mass distribution.

It is worthwhile to mention here that the mass drift in the potential energy and experimental mass distribution is also observed when a CN is formed through different channels namely ^{274}Hs formed via ^{36}S+^{238}U and ^{26}Mg+^{248}Cm channels and ^{302}120 formed via ^{64}Ni+^{238}U, ^{58}Fe+^{244}Pu channels. This is in contradiction to the multi-modal nature of fission [2] wherein the position of each mode that is determined by the nuclear shells remains

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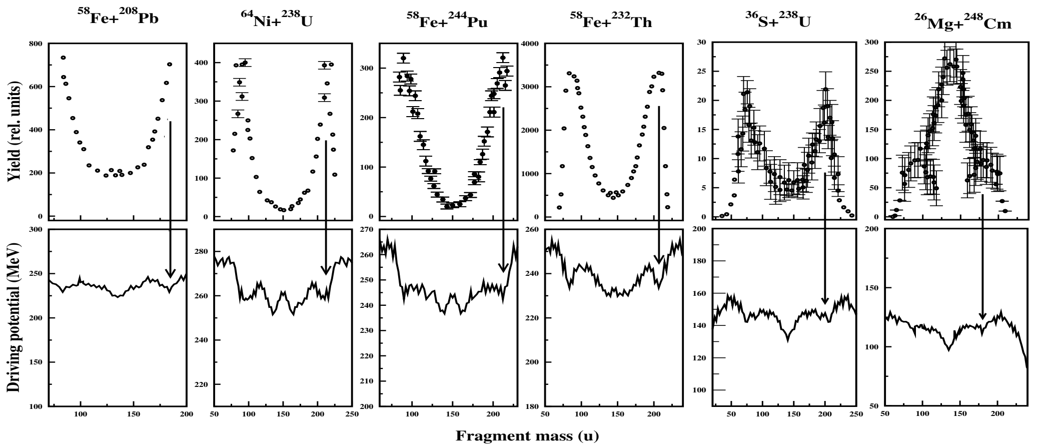

FIG. 1: Experimental mass distribution (top panel) and potential energies at contact configuration of fission fragments (bottom panel) formed in reaction ^{58}Fe+^{208}Pb [4], ^{64}Ni+^{238}U [5], ^{58}Fe+^{244}Pu [5], ^{58}Fe+^{232}Th [6],^{36}S+^{238}U [4], ^{26}Mg+^{248}Cm [4] at energies below and around the bass barrier.

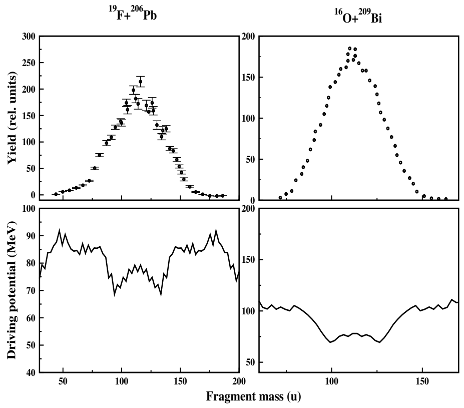

FIG. 2: Experimental mass distribution (top panel) of ^{225}Pa compound nucleus and potential energies at contact configuration of fission fragments (bottom panel) formed in reaction ^{19}F+^{206}Pb [7] and ^{16}O+^{209}Bi [8].

constant and only variation in the relative intensity of each mode has been observed [3]. FIG 2 provides support to this argument as no significant structures on the the potential energy surface have been observed for the two systems undergoing bimodal fission of ^{225}Pa. Moreover, FIG 1 presents a case study of dependence on QF on target deformation via ^{58}Fe+^{244}Pu, ^{58}Fe+^{232}Th and ^{58}Fe+^{208}Pb systems with same mass asymmetry and entrance channel coulomb factor. It is observed that indeed the driving potential and the mass drift is influenced by the target deformation around and below barrier. It is interesting to point out that at energies below barrier, a wider potential valley corresponds to a wider variance in mass width.

These observations conclude that the study of nuclear driving potential at contact configuration is an alternate tool to study the QF and indeed can be exploited to predict SHE synthesis.

References

[1] http://nrv.jinr.ru/nrv
[2] U. Brosa et.al., Phys. Rep. 197, (1990) 167
[3] E.K. Hulet et al., Phys. Rev. Lett. 56, (1986) 313
[4] M.G. Itkis et.al., Nuclear Physics A 944, (2015) 204
[5] G. N. Knyazheva et.al., AIP Conf. Proc. 1224, (2010) 377
[6] M. G. Itkis et.al., Dynamical aspects of nuclear fission (2006) 36
[7] S. Pullanhiotan et.al., EPJ Web of Conferences 163, 00047 (2017)
[8] L.M. Pant et.al., Eur. Phys. J. A 11, (2001) 47