# Fusion-Fission and associated nuclear structure effects at low energies

Deepika Jain
*School of Physics and Materials Science,*
*Thapar University, Patiala-147004, INDIA*

## Introduction

The nuclear reaction dynamics is used to explain the phenomena like fusion, fission, particle evaporation (ER), deep inelastic collision (DIC), quasi-fission (qf) etc. arising when the two nuclei collide each other under the influence of nuclear interaction. An appropriate choice of nuclear potential is extremely desirable as behavior of this strong interaction is not fully understood, despite a considerable amount of effort spend to understand this concept.

The present work deals with the formation and decay of variety of nuclear systems formed in heavy ion reactions using $\ell$-summed Wong formula [1] and dynamical cluster decay model (DCM) [2] respectively. The study is done using two types of nuclear interaction potentials; one is obtained from proximity theorem and other via Skyrme Energy Density Formalism (SEDF) [3]. The DCM contains the structural aspects of decaying nucleus via the preformation probability of the fragments, before they penetrate the interaction barrier. For the fusion reactions, the $\ell$-summed Wong formula is shown to be the same as the DCM expression with a condition of fragment Preformation $P_0^\ell$=1.

## Calculations and Results

Firstly, the use of different Skyrme forces in DCM via the nuclear proximity potential obtained from semiclassical extended Thomas Fermi (ETF) approach in SEDF under frozen density approximation is applied to study the fusion-fission dynamics of $^{132}$Sn+$^{64}$Ni$\rightarrow$$^{196}$Pt$^*$ reaction at below as well as above the Coulomb barrier energies [3]. The DCM gives an excellent fit to the measured ER and the fission cross-sections on either side of barrier, with ER data needing "barrier lowering" at below-barrier energies for each Skyrme force and the fission cross-sections show a contribution of quasi-fission (qf) at the above-barrier two/ three highest energies, depending on the type of Skyrme force. Calculations are illustrated for three Skyrme forces GSkI, SSk and SIII with the inclusion of $\beta_2$ deformations. Within $\ell$-summed extended-Wong model we observe that the GSkI and SSk forces fit the total fusion cross-section data almost exactly, whereas SIII force needs "barrier modification" in order to fit the data at below-barrier energies.

Next, an attempt is made to analyze the entrance channel effects in $^{190}$Pt$^*$ CN formed via different target and projectiles (i.e. $^{132}$Sn+$^{58}$Ni and $^{126}$Sn+$^{64}$Ni) in addition to comprehensive study on the dynamics of various isotopes of Pt$^*$ produced by stable and radioactive beams. In order to check the persistence of entrance channel independence, various versions of nuclear proximity potentials (i.e. Prox 77, Prox 88, mod-Prox 88 and Denisov 2002) and different values of level density parameter are employed in the calculations and the signature of entrance channel independence seem to sustain throughout. This observation holds good for spherical as well as deformed choice of fragmentation but the structure of potential energy surfaces change significantly as we go from spherical to quadrupole ($\beta_2$) with in the optimum orientation approach. Beside this the fission mass distribution of $Pt^*$ isotopes is investigated and consequently the barrier modification is estimated to account for the phenomena of fusion hindrance. With the neutron excess in the projectile/target, the barrier lowering ($\Delta V_B$) decreases (less negative), hence fusion hindrance also decreases in agreement with experimental observation. Alternatively the fusion hindrance phenomena is also dealt with in the framework of extended Wong model for $^{132}$Sn+$^{58}$Ni reaction at above and below the Coulomb barrier using a variety of proximity potentials. It is observed that mod-Prox 88 fits the data nicely at above as well as below the Coulomb barrier energies whereas other potentials require barrier modification in explaining the fusion hindrance phenomena.

In order to investigate the role of deformation and orientation on barrier height and barrier position, we have studied 52 colliding nuclei with mass asymmetry parameter in range of 0 to 0.96 using various proximity potentials like Prox 77, Prox 88, Prox 00, Bass 80 and Denisov DP. These potentials cover a wide range of barrier and have different isospin and asymmetry dependence. It is observed that barrier height and barrier position get modified considerably with the inclusion of deformations for all the chosen nuclear proximity potentials. In order to study the possible effect of these deformation and orientation dependent proximity potentials, an effort is made in the framework of Wong formula to address O-, Ca- and Ni- based reactions in medium mass region in reference to available data on fusion cross-sections across the Coulomb barrier. For $^{16}$O- and $^{48}$Ca-based reactions, Prox 77 gives better comparison with experimental data as compared to other potentials around the Coulomb barrier energies whereas for $^{64}$Ni-based reactions Prox 88 seems a better option. At energies above the Coulomb barrier Bass 80 and Denisov DP compete with each other [4].

Finally, the exclusive role of deformations and temperature effects are investigated independently on spin-saturated and spin-unsaturated interactions which collectively governs the nuclear potential in the semiclassical ETF approach. This exercise is made for nine even-mass $^{156-172}$Yb$^*$ isotopes formed via different incoming systems $^{56-74}$Ni+$^{100}$Mo and $^{16}$O+$^{140-156}$Sm, using spherical as well as the deformed choice of fragmentation. It is observed that the spin-orbit density interaction barrier-height ($V_{JB}$) and barrier-position ($R_{JB}$) increase systematically with increase in number of neutrons in either the projectile or target, for spherical systems. However, on inclusion of deformation effects with in optimum orientations, the barrier-height increases systematically with enhanced magnitude as compared to the spherical case, in going from $^{156}$Yb$^*$ to $^{172}$Yb$^*$ nuclear systems, except that for the oblate-shaped nuclei, the barrier height and barrier distribution does not follow the usual trend. Since deformation and orientation degrees of freedom, and the use of different Skyrme forces, change the barrier characteristics significantly, hence the effects of including the same is tested in the calculation of fusion excitation function of $^{60,64}$Ni+$^{100}$Mo and $^{16}$O+$^{144,148}$Sm reactions within framework of $\ell$-summed Wong model, which shows that the new forces GSkI and KDE0v1 respond better than the old SIII force.

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## References

[1] R. Kumar, M. Bansal, S. K. Arun, and R. K. Gupta, Phys. Rev. C **80**, 034618 (2009).

[2] R. K. Gupta, in *Cluster in Nuclei*, Lecture Notes in Physics 818, Vol. I, edited by C. Beck (Springer-Verlag, Berlin, 2010), p. 223; D. Jain, R. Kumar and M. K. Sharma, Phys. Rev. C **87**, 044612 (2013).

[3] D. Jain, R. Kumar, M. K. Sharma and R. K. Gupta , Phys. Rev. C **85**, 024615 (2012).

[4] D. Jain, R. Kumar and M. K. Sharma, Nucl. Phys. A **915**, 106-124 (2013).