Dynamics of heavy ion reactions involving compound and non compound nucleus mechanisms

Neha Grover*
School of Physics and Materials Science,
Thapar Institute of Engineering and Technology, Patiala-147004, Punjab, INDIA

Introduction

The field of nuclear reaction dynamics is advancing rapidly and the continual progress in the field has proved that there are no limits to its evolution, thus in order to expand it more, persistent efforts are being made in both experimental and theoretical domains. In view of this, a theoretical attempt is made to study the decay patterns and properties of different compound systems formed in heavy ion induced reactions (HIRs) at low energy regime. Depending upon the different reaction conditions such as entrance channel, projectile involved, and mass asymmetry etc., HIRs can be further classified into compound nucleus (CN) and non compound nucleus (nCN) reactions. The study of both CN and nCN mechanisms is inevitable as it provides a comprehensive understanding of different nuclear properties, nuclear structure and related reaction dynamics.

In the present work, the Dynamical cluster decay model (DCM) [1–3] based on quantum mechanical fragmentation theory (QMFT) [4] is applied to explore the decay paths of compound nuclei in view of complete fusion (CF) and incomplete fusion (ICF) processes. Further, the contribution of nCN component in heavy ion reactions is investigated in the form of deep inelastic collisions (DIC) and quasi fission (QF) components. Also, it is worth mentioning that in DCM, all decay processes are considered as the dynamical collective mass motion of preformed fragments through the interaction barrier. Moreover, it incorporates all essential components such as excitation energy, temperature (T), angular momentum (ℓ), deformations ($\beta_{\lambda i}$) and orientations (θ) etc.

Calculations and discussions

Firstly, the DCM is applied to study the decay profiles of ^{118,120,122}Xe* isotopes formed in ^{28}Si + ^{90,92,94}Zr reactions over a wide range of center-of-mass energy varying from E$_{c.m.}$= 63.3 - 93.5 MeV. Here, the role of deformations is examined for ^{122}Xe* by studying the behavior of fragmentation potential at two extreme energies. It is observed that the barrier characteristics and potential energy surfaces get influenced with the inclusion of quadrupole deformations (β_{2i}) and hexadecapole (β_{2i-4i}) deformations. Further, the role of isospin (N/Z ratio) is studied for ^{118,120,122}Xe* isotopes through the variation of fragmentation potential and preformation probability (P$_0$) at two comparable energies (E$_{c.m}$ $\sim$ 65.0 and 89.0 MeV). The mass distribution is found to be symmetric for all isotopes. Also, the role of projectile beam is examined in context to ^{118}Xe* and ^{123}Ba* nuclei, by changing the projectile ^{28}Si with ^{33}S. It is noticed that for both the nuclei, the light fragments are more favored at minimum ℓ-value and the change in projectile does not affect the relative contribution of ER fragments. Finally, the ER cross-sections for ^{118,120}Xe* isotopes are predicted at extreme energies, $E_{c.m.}$=63.3 and 93.5 MeV. After analyzing the decay mechanism of compound nuclei formed via CF, the DCM is applied to explore the dynamics of compound nuclei formed in ICF process.

The dynamics of ^{6}Li + ^{159}Tb and ^{17}F + ^{58}Ni reactions involving loosely bound beams is explored using DCM. All calculations are made for β_{2i}-deformed choice of fragments using the optimum orientation approach. In view of the loosely bound nature of projectiles

*Electronic address: nehagrover9823@gmail.com

(^{6}Li, ^{17}F), the comparative analysis of decay profiles associated with CF and ICF for both the reactions is studied in the form of fragmentation potential, mass distribution, penetration probability and barrier modification etc. Further, in reference to the experimental data, the decay cross-sections corresponding to CF and ICF are calculated for the considered reactions at given energy range. Interestingly, the CF and ICF cross sections within the DCM framework find nice agreement with the experimental data, and the emergence of larger neck for CF channel is possibly due to the smaller size of the composite system formed in ICF. Further, the structure of potential energy surfaces is almost similar for both CF and ICF; however, the magnitude of fragmentation potential is significantly influenced, which in turn affects the preformation probability of fragments.

Besides CN mechanisms, the nCN component is also explored in the form of deep inelastic collisions (DIC) and quasi fission (QF) processes. These processes occur prior to the formation of equilibrated compound system. Firstly, the contribution of nCN process is investigated for the light mass composite system, ^{47}V* formed in the ^{20}Ne + ^{27}Al reaction over a wide range of center of mass energy ($E_{c.m.}$=83-125 MeV). It is observed that there is strong competition between Fusion Fission (FF) and DIC components in the decay of ^{47}V* composite system. Hence, the analysis of both FF and DIC mechanisms is studied in the framework of DCM. The decay cross sections of ^{47}V* for both FF and DIC decay modes are addressed using DCM, and are found to be in agreement with the experimental data. Also, the behavior of fragmentation potential, preformation probability, penetrability and emission time etc. is examined in way to identify the most favorable isotopes contributing towards FF and DIC. Calculations of both FF and DIC are segregated on the basis of angular momentum (ℓ) windows, where $0 \leq \ell \leq \ell_{cr}$ is taken for FF and $\ell_{cr} < \ell \leq \ell_{gr}$ for DIC, as the later operates only due to the partial waves near grazing angular momentum.

Finally, the dynamics of $^{215}Fr^*$, ^{223}Pa*, ^{227}Np* and ^{233}Am* compound systems is studied in view of fission and quasi fission. Here, the decay pattern and related behavior of $^{215}Fr^*$, ^{223}Pa*, ^{227}Np* and ^{233}Am* nuclei is explored at common excitation energy, E^*_{CN} = 60 MeV. The calculations are done by considering spherical choice of fragmentation as well as with the inclusion of quadrupole (β_2) deformation. According to the available data, fission is the dominant decay mode for given nuclei, thus an attempt is made to investigate the effect of projectile mass in reference to fission decay patterns of the preactinide - ^{215}Fr* nucleus and the transactinide nuclei- ^{223}Pa*, ^{227}Np*, ^{233}Am* formed at common excitation energy, $E^*_{CN} = 60$ MeV. Besides this, the shell closure effects and the role of orientation is explored, which suggest the presence of non compound nucleus process such as the quasi fission for the compound systems under consideration. For both the compound nucleus and the non-compound nucleus processes, the results obtained using DCM are found to have nice agreement with the experimental observations. Furthermore, the isotopic and isobaric analysis is worked out so as to have comprehensive idea about the dynamical evolution of considered reactions.

Acknowledgement

I am thankful to Prof. Manoj K. Sharma for his guidance and support. The financial support from TIET, Patiala is gratefully acknowledged.

References

[1] R. K. Gupta, *et al.*, J. Phys. G: Nucl. Part. Phys. **31**, 631 (2005); Phy. Rev. C **73**, 054307 (2006); B. B. Singh, *et al.*, Phys. Rev. C **77**, 054613 (2008).

[2] N. Grover, *et al.*, Nucl. Phys. A **959**,10-26 (2017); N. Grover, *et al.*, Eur. Phys. J. A **53**, 239 (2017).

[3] N. Grover, *et al.*, Nucl. Phys. A **974**, 56-71 (2018); N. Grover, *et al.*, Phys. Rev. C **93**, 014603 (2016).

[4] J. A. Maruhn, *et al.*, Phys. Rev. Lett. **32**, 548 (1974); R. K. Gupta, *et al.*, Phys. Rev. Lett. **35**, 353 (1975).