Dynamical model calculations of elongation trajectories for ^{28}Si + ^{160}Gd and ^{12}C + ^{178}Hf reaction systems

Vikas[1] and Hardev Singh[1*]

[1] *Department of Physics, Kurukshetra University, Kurukshetra- 136119, Haryana, INDIA*

Introduction

Since last few decades, a large number of experimental as well as theoretical studies have been performed to examine the dynamical aspects of heavy ion induced fusion-fission reactions . Still, a clear understanding is not achieved, mainly in lighter preactinide region. In heavy ion induced fusion-fission reactions, the main competing processes are fusion-fission (FF) and quasi-fission (QF). In our previous work, we performed the measurements of mass-angle and mass-total kinetic energy distribution for reaction system ^{12}C + ^{178}Hf to explore the fusion-fission dynamics in lighter preactinides [1]. Kavita et al. [2], performed the measurements of fragments mass distributions for ^{12}C + ^{178}Hf and ^{28}Si + ^{160}Gd reactions populating relatively neutron deficient nuclei in lighter preactinide region, where contribution of QF was observed in the latter one. No signature of QF was found in case of ^{12}C + ^{178}Hf reaction system [1, 2]. In the present work, we have performed the dynamical model calculations of elongation trajectories for ^{28}Si + ^{160}Gd and ^{12}C + ^{178}Hf reaction systems, using HICOL code [3], to investigate the presence of quasifission, if any.

Dynamical Model Calculations

In the dynamical model, developed by Feldmeier [3], the interacting nuclei are treated as two spheres of Fermi gas, and their dynamical evolution is described by a series of shapes which consist of two spheres connected by a neck. During the collision, volume of the shape remains conserved so that the mass and charge density remain constant. The shapes of fusing nuclei during their dynamical evolution are determined by three parameters, unique for each shape, which are defined as:

(i) the distance between the two nuclei (S) or elongation

S = distance between the two sphere centers

(ii) the neck coordinate (σ)

$$\sigma = \frac{V_0 - \frac{4\pi R_1^3}{3} - \frac{4\pi R_2^3}{3}}{V_0} \qquad (1)$$

(iii) the mass asymmetry (Δ)

$$\Delta = \frac{R_1 - R_2}{R_1 + R_2} \qquad (2)$$

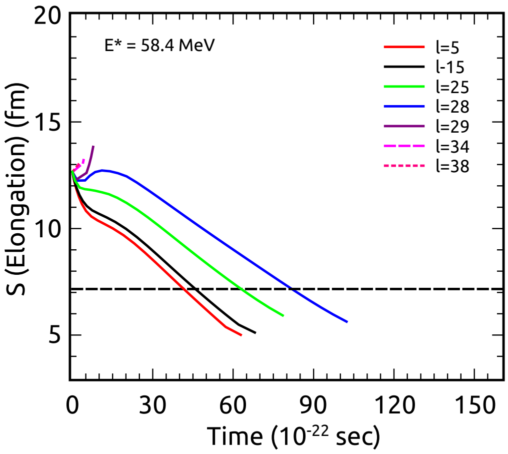

FIG. 1: The separation (S) of colliding nuclei as a function of time at different angular momentum (l) values for reaction ^{28}Si + ^{160}Gd, at excitation energy 58.4 MeV.

*Electronic address: hardev79@gmail.com

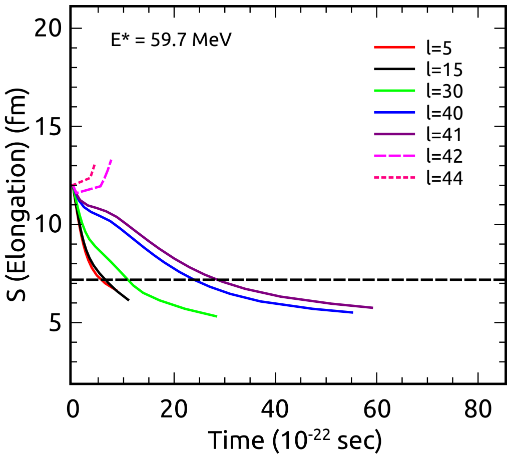

FIG. 2: The separation (S) of colliding nuclei as a function of time at different angular momentum (l) values for reaction ^{12}C + ^{178}Hf, at excitation energy 59.7 MeV.

where V_0 is the total volume of the system, R_1 and R_2 are the radii of two colliding nuclei. In addition to three shape degrees of freedom, HICOL code also included three rotational degrees of freedom (intrinsic and relative) of dinuclear complex. Using these shape and rotational degree of freedom, the evolution of fusing nuclei is followed by solving the Langevin equations of motion. Here, one-body dissipation is assumed to be the predominant mechanism.

For reaction systems, ^{28}Si + ^{160}Gd (at excitation energy (E*) 58.4 MeV) and ^{12}C + ^{178}Hf (at E* = 59.7 MeV), the elongation of interacting nuclei as a function of evolution time at different angular momentum (l) values, is shown in Fig. 1 and 2, respectively. The dashed black line in Figs. 1 and 2 represents the radius of CN ^{188}Pt and ^{190}Pt, respectively, obtained using relation $R = R_0A^{1/3}$. For both studied reactions, the maximum angular momentum l_{max} values were obtained from coupled channel code CCFULL [4]. For ^{28}Si + ^{160}Gd and ^{12}C + ^{178}hf systems at the studied energies, the calculated (l_{max}) values are $\approx 49\hbar$ and $42\hbar$, respectively. It was observed that the trajectories at lower l values upto $l = 28\hbar$ (for ^{28}Si + ^{160}Gd) and $42\hbar$ (for ^{12}C + ^{178}Hf) lead to the formation of an equilibrated compound nucleus or complete fusion, where elongation of the system is comparable or less than the size of compound nucleus. Whereas, for trajectories at higher l values (ie., $l > 28\hbar$ (for reaction ^{28}Si + ^{160}Gd), and $l > 42\hbar$ ^{12}C + ^{178}Hf), the interacting nuclei separated quickly before getting fused together to form a composite system, indicating deep inelastic or non-compound nucleus processes. Thus, HICOL code calculations predict that trajectories for $l \leq 28\hbar$ (for ^{28}Si + ^{160}Gd), and $l \leq 40\hbar$ (for ^{12}C + ^{178}Hf) correspond to the formation of an equilibrated compound nucleus. Trajectories for higher l values correspond to deep inelastic collision or non-compound nucleus processes. In both systems, HICOL code calculations predict no quasifission contribution, which contrasts with the quasi-fission observed in ^{32}S + ^{182}W [5], ^{20}Ne + ^{205}Tl and ^{16}O + ^{209}Bi [6] systems. These findings are also inconsistent with the QF signatures seen in the mass distributions measurements in case of ^{28}Si + ^{160}Gd system [2].

Acknowledgments

One of the authors, Vikas acknowledges the Council of Scientific and Industrial Research (CSIR), New Delhi, for providing financial support through CSIR-SRF Fellowship.

References

[1] Vikas et al., J. Phys. G: Nucl. Part. Phys. **51**, 035103 (2024).
[2] Kavita et al., Phys. Rev. C **100**, 024626 (2019).
[3] H. Feldmeier, Rep. Prog. Phys. 50, 915 (1987).
[4] K. Hagino et al., Comput. Phys. Commun. **123**, 143 (1999).
[5] P. N. Patil et el., Phys. Rev. C **102**, 034618 (2020).
[6] K. Atreya et al., Phys. Rev. C **6**, 034615 (2023).