Systematic Study of Entrance Channel Effects in ^{200}Pb via Dynamical Model Calculations

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Introduction

The stability of heavy nuclei leading to the formation of superheavy elements is a topic of considerable interest in the past few years. It has been observed that in the heavy mass regions, there is onset of various non-compound nucleus (NCN) processes such as quasifission which hinders the compound nucleus formation.

In case of mass symmetric systems, the fusion is hindered because of long formation time of the compound nucleus as mass is transferred from the target to projectile. This implies that entrance channel plays an important role in the fusion reaction. The experimental signature of entrance channel in heavy mass regions was found via evaporation residue cross section and spin distribution measurements [1], where it was observed that ER cross sections and moments of gamma multiplicity distribution of ^{16}O+^{184}W system were significantly higher than those of ^{19}F+^{181}Ta at higher Excitation energies (E*) . Nasirov et al. [2] in a theoretical calculation pointed out the presence of quasifission and fast fission like components in ^{19}F+^{181}Ta system at large beam energy that causes hinderance to the fusion. To test it further Chaudhury et al.,[3] measured the mass distribution in the excitation energy range of 75 to 55 MeV and ruled out quasifission through a perfectly Gaussian mass distribution measurements.

In this study we have done theoretical calculations using both statistical model and dynamical model in order to resolve the above ambiguity and understand the entrance channel effects in heavy ion induced reactions

Statistical model calculations

The statistical model has been widely used to understand the decay of the Compound nucleus. This model assumes that all the possible decay channels are equally likely and are governed by the factors such as the density of final states and barrier penetration factors. The standard form of level density formula is

$$\rho(E*,l) = \frac{2l+1}{24}\left[\frac{\hbar^2}{2I}\right]^{3/2}\frac{\sqrt{a}}{E^{*2}}\exp(2\sqrt{aE^*}) \qquad 1)$$

where I is the rigid body moment of inertia and l is the angular momentum of the CN, ‘a’ is the level density parameter. BW-fission width is used to obtain fission probability and is given by:

$$\Gamma_{BW} = \frac{1}{2\pi\rho(E^*)}\int_0^{E^*-V_B} d\epsilon\,\rho(E^*-V_B-\epsilon) \qquad 2)$$

Normalized ER cross-sections as function of E* are calculated for ^{19}F+^{181}Ta and ^{16}O+^{184}W reactions both populating ^{200}Pb for different values of barrier scaling factor K are shown

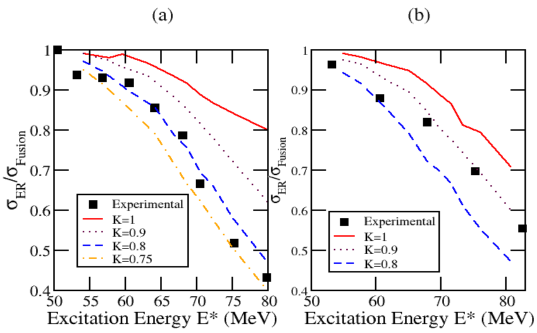

Figure 1. Experimental Normalized ER cross sections (Filled squares) vs E* plotted with the theoretical results obtained from the statistical model calculations after varying K values for (a) ^{19}F+^{181}Ta and (b) ^{16}O+^{184}W reactions

The lower K values required to fit the experimental ER cross-section data for ^{19}F+^{181}Ta as compared to ^{16}O+^{184}W reaction indicates the presence of NCN processes in the former reaction. A dynamical model HICOL code is employed in order to estimate the contribution of NCN processes in the fusion of the nuclei in above two reactions.

Dynamical model calculations

In the present work dynamical model HICOL code calculations developed by Feldmier [4] have been done in order to estimate the contribution of NCN processes in ^{19}F + ^{181}Ta and ^{16}O + ^{184}W reactions both populating ^{200}Pb

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nucleus. Model assumes that two spheres are connected by a neck and their dynamical evolution described by a sequence of shapes where the mass and charge density remain constant.The intermediate di-nuclear compound nucleus formed can be described by three parameters, viz Δ, the asymmetry parameter; S, elongation; and σ, the neck coordinate, which are defined as

S = distance between the two sphere centres

$$\sigma = \frac{V_o - (4\pi/3)R_1^3 - (4\pi/3)R_2^3}{V_o} \quad 3)$$

$$\Delta = \frac{R_1 - R_2}{R_1 + R_2} \quad 4)$$

Here V_0 is the volume of nuclei and is considered to be independent of S, σ and Δ whereas R_1 and R_2 are the radii of two nuclei.

Results and discussion

Statistical model calculations have been performed for ^{200}Pb system in the excitation energy range of 55-80 MeV . In Figure 1(a) for ^{19}F+^{181}Ta reaction, reduction in the liquid drop model fission barrier is found to be necessary in order to fit the experimental normalized ER cross-section. The barrier height had to be reduced to K=0.75 in order to fit the experimental data at high energies. While for ^{16}O+^{184}W , it can be seen from figure 1(b) that the experimental ER cross-section can be reproduced even by K=0.9 at high energies. This indicates the presence of NCN processes at high excitation energies in case of ^{19}F+^{181}Ta system. Dynamical model HICOL code is used to estimate the amount of quasifission present in both the reactions at E* of 65-80 MeV.

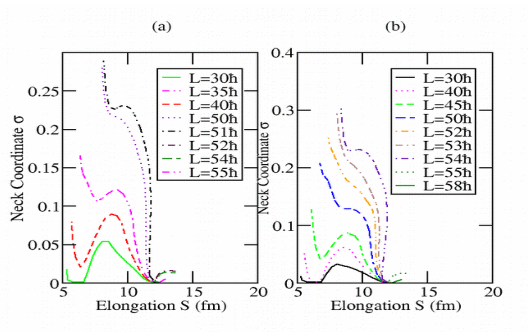

Figure2:Neck coordinate versus elongation for fusion and non fusion trajectories are shown for ^{19}F+^{181}Ta and ^{16}O+^{184}W in figure (a) and figure (b) respectively

Figure2 shows typical fusion and nonfusion trajectories in the (S,σ) plane for selected angular momentum values for both the reactions at E* = 75 MeV. From Figure 2(a), it is observed that the trajectories for l= 30ħ, 35ħ ,40ħ ,50ħ and 51ħ correspond to typical fusion. While the l=52ħ ,54ħ and 55ħ corresponds to nonfusing trajectories for which the composite system reseperates into two symmetric fragments without reaching the fusion stage. So dynamical model predicts that trajectories corresponding to angular momentum (30-51)ħ corresponds to fusion trajectories and (52-55)ħ corresponds to NCN processes. Hence HICOL model predicts around 8% quasifission contribution in case of ^{19}F+^{181}Ta reaction at excitation energy of 75 MeV. In figure 2(b), it can be seen that angular momentum corresponding to (30-54)ħ leads to fusion trajectories and (55-58)ħ leads to NCN processes which shows that around there is about 6% quasifission contribution in case of ^{16}O+^{184}W reaction. Similarly, we have calculated the QF contribution at other energy points and it is found that for the reaction ^{19}F + ^{181} Ta, QF contributes about 6 and 10% at E* = 65 and 80 MeV respectievly while for ^{16}O + ^{184}W it is found to be 5 and 7 % at E* = 65 and 80 MeV respectively. So we observe that QF contribution increases with increase in the excitation energy and the increase in QF contribution is more for ^{19}F + ^{181}Ta than for the ^{16}O + ^{184}W reaction which indicates the presence of entrance channel effects in the systems which are not very different from each other in terms of entrance channel mass asymmetry.

Acknowledgement

One of the authors BRB acknowledges the Science and Engineering Research Board (SERB), Govt. of India, for support through Contract No. EMR/2017/004722.

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