Fission before mass equilibration in heavy ion reactions

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Introduction

Presence of quasifission (QF) in heavy-ion induced reactions is a major hurdle in the synthesis of heavier and heavier elements. Many recent experiments have shown that QF is present in systems where it is not expected theoretically [1–5]. Three prominant signatures of quasifission process are : anomalously large angular anisotropies, broken fragment mass symmetry between forward-backward directions in the center of mass, and an increase in width of the fragment mass distribution compared to the widths expected for fusion-fission [6]. For Compound Nucleus (CN) fission, we expect that the width of the fragment mass distribution is independent of the entrance channel. In quasifission reaction, however, recent experiments [1–5] reported anomalous brodening of mass distribution for more symmetric systems forming the same compound nucleus in fissile (fissility ∼ 0.8) and less fissile (fissility ∼ 0.7) systems. These measurements have not shown any mass-angle correlation, but width of fission-fragment mass distribution was found to be consistently higher than that expected for fusion-fission. Fig.1, shows the plot of width of mass distributions as a function of excitation energy for various compound systems formed by different target-projectile combinations obtained from [1–5]. A theoretical model based on time scales of equilibration is being developed to explain the anomalous mass distributions in these systems in a consistent manner.

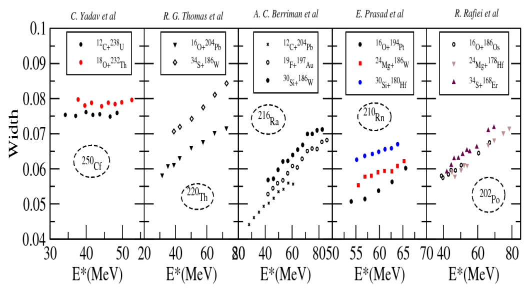

FIG. 1: Width as a function of compound nucleus excitation energy for various systems [1–5].

Model

Fig. 2 shows plot of potential energy surface calculated using Swiatecki formalism [7], in which we schematically show the trajectories while relaxing in mass and (ρ) degrees of freedom, escaping before forming mass equilibrated compound system and may lead to broader mass distributions. We assume that total yield is an admixture arising from two componets, viz the compound nucleus (CN) and non-compound nucleus (NCN).

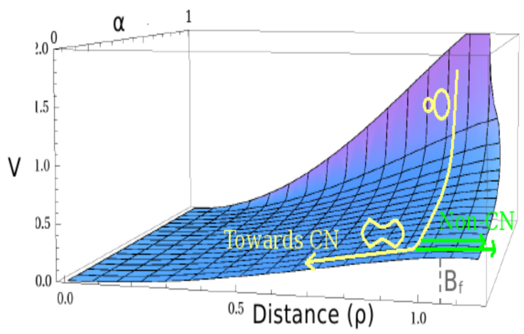

FIG. 2: Schematic illustration of trajectories escaping compound nucleus formation path and giving broader mass distribution.

The total yield can be written as,

$$Y = f_{ncn}G_1 + f_{cn}G_2 + f_{ncn}G_3 \quad (1)$$

where gaussian G_2 with centroid at mass ratio equal to 0.5, corresponds to compound nu-

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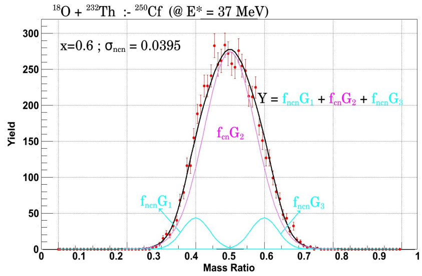

FIG. 3: Mass ratio distribution data for ^{18}O + ^{232}Th reaction at E* =37 MeV fitted with three gaussian fission yield model amd fitting parameters x and σ_{ncn} are indicated.

cleus reaction, and the gaussians G_1 and G_3 with centroid at mass ratio 0.4 and 0.6 respectively, corresponds to mass non-equilibrated component responsible for broadening of mass distribution in symmetric reaction channels which was used to form the same CN. The width of gaussian in G_1 and G_3, σ_{ncn} is the fitting parameter and width in gaussian G_2, (i.e., σ_{cn}) obatined from fusion-fission reaction. f_{ncn} is the fraction of mass non-equilibrated component and is determined by description given below.

If the equilibration time in mass degree of freedom is τ_m (5×10^{-21} sec) [8], then fraction P_{NCN} ($P_{NCN} = 2f_{ncn}$) which escapes by mass non-equilibration before reaching complete mass equilibrated CN is given by

$$P_{NCN} = [1 - exp(-\tau_m/\tau_f)] \quad (2)$$

where τ_f is the fission time given by

$$\tau_f = \frac{2\pi}{\omega_{eq}} exp\Big(\frac{xB_f}{T}\Big) \quad (3)$$

where ω_{eq} is 10^{21} sec^{-1}, B_f is the average fission barrier, T is the temperature. The fission barrier scaling parameter x is also treated as fitting parameter.

The fitting parameters x and σ_{ncn} obtained by χ^2 minimization. Fig. 3 shows the plot, where mass ratio distribution data for ^{18}O + ^{232}Th reaction at E*=37 MeV has been fitted with three gaussian model. Fitting parameters x and σ_{ncn} obatined for ^{18}O + ^{232}Th reaction has variation from 0.6 to 0.96 and from 0.034 to 0.04 respectively with respect to E*. Fig. 4 shows the plot of the calculated width along with the data for the reaction ^{18}O + ^{232}Th for a value of x=0.8 and σ_{ncn}=0.036. Detail description and results for all the systems will be discussed at symposium.

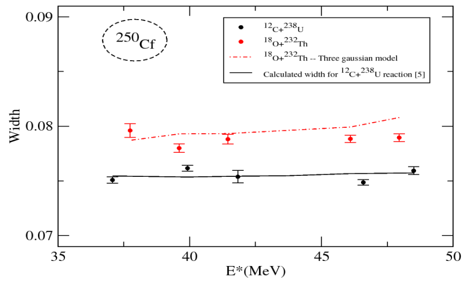

FIG. 4: Width of fission-fragment mass distribution vs E*(MeV). The red dash-dotted line is three gaussian model prediction for non-CN reaction.

Acknowledgments

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