Statistical model calculations of pre-scission neutron multiplicity for near super-heavy nuclei

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Introduction

Nearly half a century ago, the experimental efforts aiming at the formation of super-heavy nuclei followed the prediction of an island of super-heavy nuclei with enhanced stability due to shell effects [1]. Such experiments are extremely challenging as the formation of heavy and super-heavy evaporation residues (ERs) are suppressed not only by equilibrium fission, but also by a non-equilibrium process called quasi-fission. The main objective in the heavy element production is to identify those variables that hinder compound nucleus (CN) formation. This problem can be better addressed by measuring the characteristics of the quasi-fission events. Properties of the entrance channel, in particular the entrance channel mass-asymmetry and the deformation of colliding nuclei, play a major role in the reaction dynamics of quasi-fission process.

With these motivations, we have planned to carry out two experiments $^{48}Ti+^{208}Pb$, $^{28}Si+^{232}Th$ populating near super-heavy CN ^{256}Rf, ^{260}Rf (Z=104) respectively to study their reaction mechanism using neutron multiplicity as a probe. In the present work, we are reporting the exploratory calculations of pre-scission neutron multiplicity for these systems using a statistical model code [2].

Statistical Model Calculations

In this work, we have performed statistical model calculations for three systems $^{48}Ti+^{208}Pb$, $^{28}Si+^{232}Th$ and $^{20}Ne+^{240}Pu$ populating near super-heavy compound nuclei $^{256,260,260}Rf$ respectively at same excitation energies ranging from 55 MeV to 103.8 MeV using statistical model code.

Important ingredients used in the statistical model code are: 1. the nuclear density of states, 2. the Bohr-Wheeler (BW) fission Width, 3. the Kramers' fission width. The nuclear level density $\rho(E)$ plays a central role in the theoretical modelling of decay of hot CN. The standard form of the level density formula can be written as:

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

where ℓ is compound nuclear spin. I is the rigid body moment of inertia of the CN and the quantity *'a'* is called the level density parameter which, according to the Fermi gas model, is related to the nuclear temperature T by the equation $E^* = aT^2$. With the above description of the density of states and the level density parameter, BW fission width can be calculated from the following expression:

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

The Kramers' fission width is given as [3]:

$$\Gamma_K = \frac{\hbar\omega_g}{2\pi} exp(-V_B/T)\left\{\sqrt{1+\left(\frac{\beta}{2\omega_s}\right)^2} - \frac{\beta}{2\omega_s}\right\}$$

where β is the reduced dissipation strength, V_B is the fission barrier height, ω_g and ω_s are the frequencies of the harmonic oscillators at the ground state and at the saddle configurations.

In the present work, we have used the spin distribution of the CN from the empirical formula given in Ref. [4]. All the partial widths are calculated in the code and the decay of a CN is followed using Monte-Carlo method. The multiplicities of the pre-scission neutrons are thus obtained from the statistical model code.

Results and Discussion

The excitation function of pre-scission neutron multiplicity are calculated for three systems (Figs.1, 2 and 3) using both BW and

Kramers' width for different values of β. Fig.1 shows the results for the ^{20}Ne+^{240}Pu system for which experimental data is available [5] at two excitation energies. We first note that BW fission width severely underestimates the experimental multiplicities. A value of β = 8×10^{21} sec^{-1} is found to be necessary to fit the experimental data.

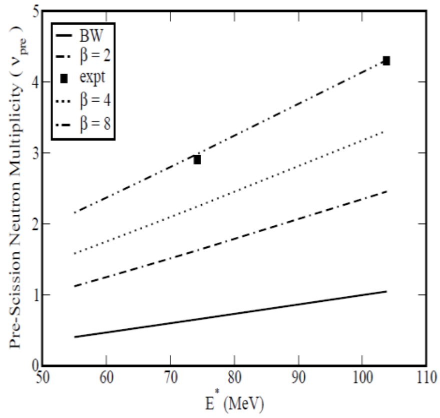

Fig.1 Pre-Scission neutron multiplicities calculated using BW width and Kramers' width for ^{20}Ne+^{240}Pu system with different β values

Assuming the above value of β to be appropriate for the CN with mass ~ 260 and in the considered excitation energy range, we next show the pre-scission neutron multiplicity for the ^{48}Ti+^{208}Pb in Fig.2 calculated with β = 8×10^{21} sec^{-1} and also for a few lower values of β.

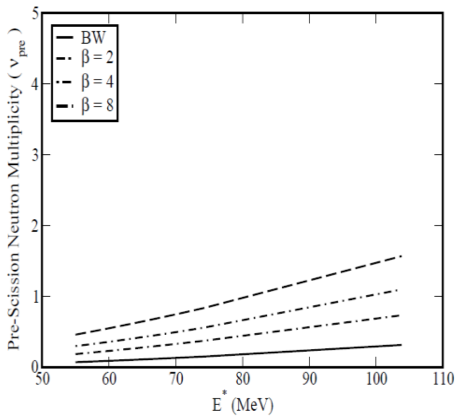

Fig.2 Pre-Scission neutron multiplicities calculated using BW width and Kramers' width for the ^{48}Ti+^{208}Pb system

Similar calculated results for ^{28}Si + ^{232}Th are given in Fig.3.

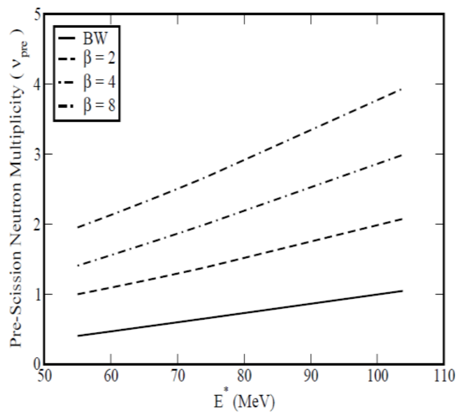

Fig.3 Pre-Scission neutron multiplicities calculated using BW width and Kramers' width for the ^{28}Si+^{232}Th system

The calculated results in Figs.2 and 3 are exploratory in nature. They provide us an estimate of pre-scission neutron multiplicities which one might expect in an experiment. We observe that the pre-scission multiplicity reduces with increase in projectile mass. This evidently reflects the effect of lowering of fission barrier at higher compound nuclear spin populated by heavier projectiles. The experimental multiplicities may however be still smaller for heavier projectiles due to quasi-fission. We aim to investigate these features in our planned experiments in near future.

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