Systematic study of pre-scission neutron multiplicity for ^{48}Ti + ^{232}Th reaction using statistical model code

Shruti[1,*], B.R. Behera[1], Ruchi Mahajan[1] , Meenu Thakur[1], Santanu Pal[2]
[1]Department of Physics, Panjab University, Chandigarh-160014, INDIA
[2]CS-6/1, Golf Green, Kolkata 700095, India (Formerly with VECC, Kolkata)
email:shrutinarang.sn@gmail.com

Introduction

In the recent years there is a remarkable progress in the experimental research of synthesis of superheavy elements. Different approaches have been employed for the clarification of the reaction mechanism in the superheavy mass region and to predict the favourable conditions (projectile-target combination and beam energy values) to synthesize new elements. An appropriate understanding of the reaction dynamics is a pre-requisite for the formation of SHE. These studies involve the measurements of fission and evaporation residue excitation functions and their analysis using various useful models. In order to extend the limit of periodic table of elements intense theoretical and experimental aspects have been explored in last few decades [1-3]. The dominating decay channels in heavy and super-heavy nuclei are the fusion-fission and quasi-fission processes. The major reasons for studying fusion-fission reactions are the formation of super heavy elements (SHE) and to have detailed understanding of the evolution and decay of the compound nucleus (CN). The predicted fission barriers for SHE are about 3-10 MeV. Due to high fissility of SHE caused by the relatively small fission barrier only a minor part of the fusion cross-section is expected to fall into the ER channel and the excited CN formed mainly undergoes fission (CNF) [4]. The competition between QF and FF processes demonstrates a complex behavior in the fission dynamics of the SHE. Neutron multiplicity measurements are very much useful for learning about the nuclear dynamics involved in the formation of nuclei in the superheavy mass region because it acts like a clock and provides the time-scale of the QF and FF processes separately.

In the present study we are reporting pre-scission neutron multiplicity (M_{pre}) values for the ^{280}Cn super-heavy compound nucleus at excitation energy of 57.4 MeV and bombarding energy of 272.7 MeV. This CN is populated by the reaction of ^{48}Ti+^{232}Th system. Very recently M.Thakur et al. [5] have calculated the pre-scission neutron multiplicity for the reaction of ^{48}Ti+^{208}Pb populating near super-heavy compound nuclei ^{256}Rf with E*=57.4 MeV (E_{lab} =273.1 MeV) and observed a value 0f 0.25 including a saddle-to-scission contribution of 0.21. We have planned an experiment to study reaction dynamics of a super-heavy element copernicium so the present calculations will provide an useful insight regarding the dynamics of the system under consideration.

Statistical model calculations

The statistical model of compound nucleus decay is the backbone for theoretical understanding of heavy ion induced fusion-fission reactions. The decay of the CN can be successfully described by the statistical model. The model assumes that all possibilities for decay are intrinsically equally likely and governed by factors such as the density of the final states and barrier penetration factors. In this framework of statistical model code neutron multiplicity calculations have been performed assuming that the system forms a fully equilibrated CN after the capture of projectile and contribution from non-compound nuclear processes such as QF is negligible. The standard form of level density formula can be written as[6]:

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

where $\mathfrak{I}$ is the rigid body moment of inertia of the CN, ℓ is the angular momentum of CN, 'a' is the level density parameter and it is related to the nuclear temperature 'T' by the expression $E^* = aT^2$ according to Fermi gas model. In order to obtain fission probability, Bohr-Wheeler fission width can be estimated from the following equation[6]

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

where V_B is the fission barrier and ϵ is the kinetic energy at the saddle point. The Kramer's fission width is given as [8]

$$\Gamma_K = \frac{\hbar\omega_g}{2\pi}\exp(-V_B/T)\left\{\sqrt{1+\left(\frac{\beta}{2\omega}\right)^2}-\frac{\beta}{2\omega s}\right\} \qquad (3)$$

Following the same approach, in the present report we aim to calculate the ν_{pre} values for above mentioned reaction. The calculations have been carried out for a large number of events using the statistical model code in which integral form of fission width is used on the potential energy profile and shell effect is considered in the level density parameter. Shell correction in the fission barrier is also included.

Result and discussion

As a representative case, we have performed statistical model calculations for the system ^{48}Ti + ^{232}Th with E* =57.4 Mev which populates a super-heavy compound nucleus ^{280}Cn at bombarding energy of 272.7 MeV [9]. The CN ^{280}Cn is a super heavy one with practically zero LDM barrier and is entirely shell supported ncleus. It fission almost immediately. Also for compound nuclei formed at higher excitation energies (>50 MeV), the emission of particles (n,p,α) becomes significant and is strongly related to dissipation. Hence we carried out statistical model calculation for ^{280}Cn where pre-scission neutron multiplicity is obtained using Bohr-Wheeler and Kramer's fission width by providing input values of deformation parameter β_2 . The variation of ν_{pre} for different values of β (reduced dissipation strength) are shown in figure below:

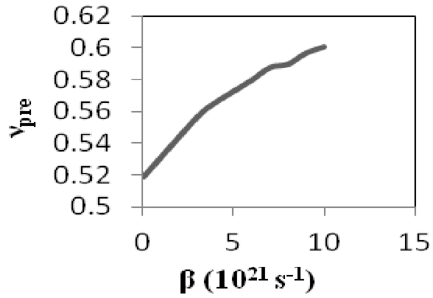

Fig1: Variation of pre-scission neutron multiplicity for different values of β

From this figure it is clear that ν_{pre} increases with increasing value of β. Detailed calculations for this reaction will be presented in conference.

References

[1] J.H. Hamilton *et al.*, Annu. Rev. Nucl. Part.Sci **63**,383 (2013)
[2] L. Donadile *et al.*, Nucl. Phys. A **656**,(1999)
[3] Y. Aritomo *et al.*, Nucl. Part. Phys. **32** (2006)
[4] M.G. Itkis et al., Nucl. Phys. A **944** (2015)
[5] M.Thakur et al., Phys. Rev.C **98**, 014606 (2018)
[6] A. Bohr *et al.*, Nuclear structure Vol. I (Benjamin Press, New York,1969)
[7] N. Bohr *et al.*, Phys. Rev. **56**, 426 (1939)
[8] H.A.Kramers,Physica (Amsterdam) **7**, 284 (1940)
[9] Jhilam Sadhukhan and Santanu Pal, Phys. Rev. C **78**,011603 ® (2008); Phys. Rev. C **79**, 019901 (E) (2009)