Statistical model calculations for nuclear fission processes

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Introduction

Study on heavy ion nuclear reactions involves many complex processes, which have been under study for many decades, but yet not fully understood, because of the complexities involved. Theoretical modeling of fission process is an important step towards a better understanding of fission dynamics of highly excited compound nuclei formed in heavy-ion induced fusion-fission reactions. During the path of fusion-fission reaction, neutron emission is one of the dominant decay channels. Neutron multiplicity measurement has been used as an effective probe to study such kind of dynamical evolution of nuclear systems. In the present work, we have calculated the neutron multiplicities of the compound nucleus of ^{208}Rn and ^{196}Pt at different excitation energies by the statistical model of nuclear fission.

Statistical Model Calculations

The statistical model for nuclear fission is used extensively to understand the nuclear decay mechanism [1]. The heavy ion induced nuclear reaction involves the formation of compound nucleus of very high excitation energy and angular momenta, which can undergo fission by breaking apart in two pieces or can approach its ground state via evaporation of particles such as neutron, proton, alpha and gamma. The pre-scission multiplicities of neutron and charged particles in particular are very significant tools to estimate the time scale of fission process. Therefore, in the framework of statistical model calculations, emission of neutrons, protons, alpha and gamma rays are considered along with fission as the possible decay channels of a compound nucleus [2]. Statistical model calculations for neutron multiplicity have been performed assuming that the system forms a fully equilibrated compound nucleus after the capture of projectile and contribution from non-compound nuclear processes such as quasi-fission is negligible. For calculating the fission probability, Bohr-Wheeler fission width can be estimated by [1]

$$\Gamma_f^{BW} = \frac{1}{2\pi\rho_{gs}(E_i)} \int_0^{E_i - V_b} \rho_{sad}(E_i - V_b - \varepsilon) d\varepsilon \quad (1)$$

where E_i is the energy of the initial (ground) state, V_b is the fission barrier and ε is the kinetic energy at the saddle point, $\rho_{gs}(E_i)$ is the level density at the ground state, $\rho_{sad}(E_i - V_b - \varepsilon)$ is the level density at the saddle point. The standard form of the level density can be written as[3]

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

where $\Im$ is the moment of inertia, l is the angular momentum of compound nucleus, a is the level density parameter which is related to the nuclear temperature by $E = aT^2$. The time evolution of a compound nucleus (CN) was followed in the statistical model code by using the widths of all the possible decay modes. After each successive decay the intrinsic energy and angular momentum is recalculated for the daughter nucleus and the procedure is followed until the fission or intrinsic energy becomes less than the particle binding energy and evaporation residue(ER) formed. Using

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this approach, the number of light particles as well as photons are counted for each fission event. In such a calculations, the number of particles emitted during saddle to scission can also be calculated. The calculations have been performed over a large number of events with different values of initial angular momentum sampled from a given fusion cross-section and the multiplicities of the pre and post-scission neutrons are obtained from the statistical model code.

Result and Discussion

In this work, we have performed statistical model calculations for two systems ^{48}Ti+^{160}Gd and ^{16}O+^{180}Yb populating ^{208}Rn and ^{196}Pt, respectively, in the excitation energy range of $\simeq$ 75-114 MeV. The fission width of the compound system depends on the height as well as on the curvature of the fission barrier. The potential profiles for various isotopes of Pt and Rn with elongation, calculated using finite range LDM. The potential profiles of Rn isotopes are shown in Fig.1.

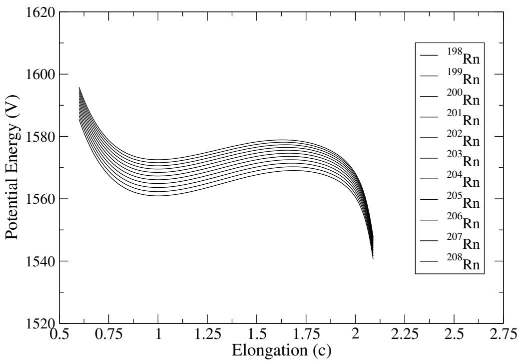

FIG. 1: Finite range LDM potentials as a function of elongation for different isotopes of Rn nuclei, from top to bottom in ascending values of mass numbers.

The calculated excitation functions of pre and post-scission neutron multiplicities, using the BW width are shown in Fig.2 for ^{48}Ti+^{160}Gd$\rightarrow$^{208}Rn and ^{16}O+^{180}Yb $\rightarrow$ ^{196}Pt. The fissility parameters [1] for ^{208}Rn and ^{196}Pt are 0.738 and 0.658 respectively. The pre-scission neutron multiplicities for ^{208}Rn system is lesser then ^{196}Pt which indicates the less time taken by the ^{208}Rn system during its path to fission [4], because of higher fissility and population of higher spin values for ^{208}Rn. Consequently, post-scission neutron multiplic-

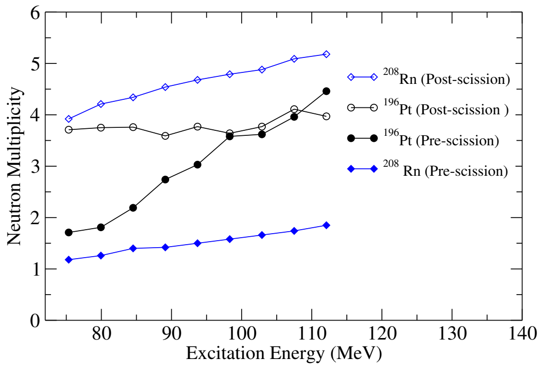

FIG. 2: Pre and Post-scission neutron multiplicities for CN of ^{208}Rn and ^{196}Pt at different E^*

ities for ^{208}Rn are larger as compared to ^{196}Pt because of the value of available excitation energy for fission fragments is more for ^{208}Rn system. The system ^{16}O+^{180}Yb $\rightarrow$ ^{196}Pt also shows stronger excitation energy dependence in pre-scission neutron emission as compared to ^{48}Ti+^{160}Gd$\rightarrow$^{208}Rn.

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