Time scale of nuclear fission in transition state model

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Introduction

Pre-scission neutron multiplicity (n_{pre}) acts as a sensitive clock for fission time scale of compound nuclei (CN) populated in fusion-fission reactions. Different studies exist in literature which demonstrate that a fission delay is required in standard statistical model calculations in order to reproduce the experimental values of n_{pre} [1] However, it was also observed that the time scales obtained from n_{pre} measurements are not consistent with the evaporation residue (ER) or fission cross-sections [2-4].

The time scale for fission can be expressed as the sum of several time intervals as follows,

$$\tau_{fission} = \tau_{form} + \tau_{gs} + \tau_{ss}$$

where τ_{form} is the time associated with the formation of a CN, τ_{gs} is time interval for CN shape evolution from equilibrium configuration or ground state to the last outward crossing of the transition state or the saddle point towards the scission. τ_{ss} is the time interval for the CN to evolve from the saddle point to reach the scission. Evaporation of particles or photons can take place during all the above time intervals. Particles can further be emitted during the acceleration phase of the fission fragments which are usually included in the experimental pre-scission multiplicity values. However, we shall not consider this post-scission emission in the present work. Further, τ_{form}contribution will also not be included here. τ_{gs} depends on the various decay widths including fission whereas post-saddle dynamics determines τ_{ss}.

In the present work, we have addressed the pre-saddle time-scale by using transition-state model of fission [5] which assumes that the compound nucleus is committed to undergo fission when it crosses the saddle point configuration during τ_{gs} and further takes τ_{ss} to split into fission fragments. To this end, we have performed statistical model (SM) calculations for the reactions $^{12}C+^{194,198}Pt$ populating the CN $^{206,210}Po$ with N=122 and 126 respectively.

Statistical Model Calculations

The statistical model used here assumes that the compound nucleus can decay either through the emission of light particles (neutron, proton, α-particles), γ-rays or through the fission process. The Weisskopf formula for the particle and γ-decay widths and the fission width Γ_K where $\Gamma_K = \Gamma_{BW}\left(\sqrt{1+(\beta/2\omega)^2} - \beta/2\omega\right)$, as given by Kramers [6] are used in the present calculation. Here Γ_{BW} is the Bohr-Wheeler fission width and β is the reduced dissipation coefficient. ω is the harmonic oscillator potential frequency osculating the saddle region potential. β and τ_{ss} are the only adjustable parameters in our calculation. Shell effects are also included in the calculations. The details of the statistical model code VECSTAT used here can be found elsewhere [2].

Results and Discussion

The experimental ER cross-sections and n_{pre} for the present systems are taken from literature and are analyzed here. From Fig. 1, it is observed that the ER cross-sections are fitted well using β =2 zs^{-1} for both the systems. Further, the excitation functions of n_{pre} are fitted by keeping $\beta = 2\ zs^{-1}$ and by varying τ_{ss}. It is seen in Fig.2 that for τ_{ss} = 100 ħ/MeV, the multiplicities are well reproduced for both the cases except for the highest energy data for $^{12}C+^{194}Pt$.

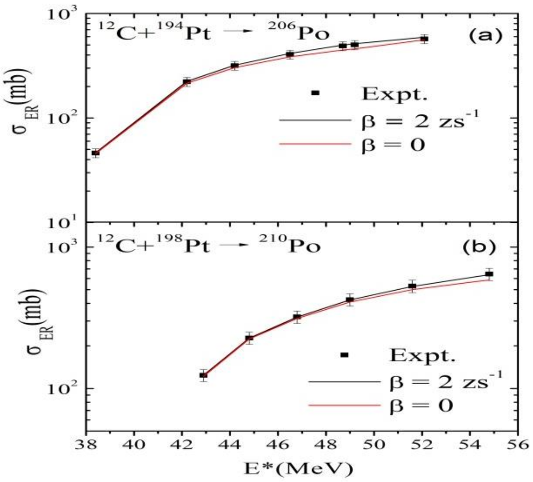

Fig. 1

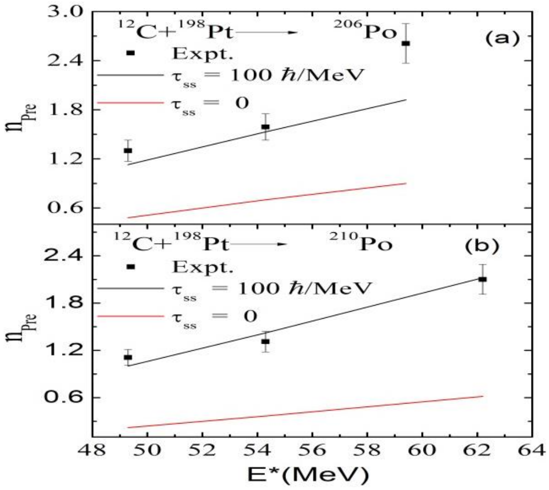

Fig. 2

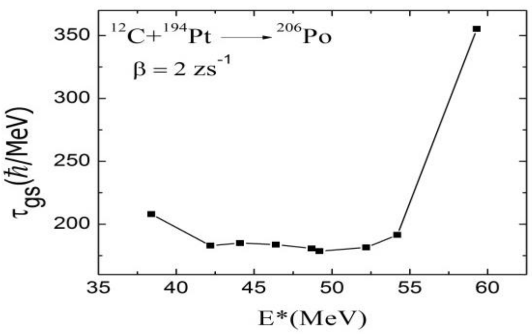

Fig. 3

The time interval τ_{gs} obtained as the average over a large number of fission events is shown for ^{206}Po as a function of excitation energies (E*) in Fig.3. It is interesting to see that τ_{gs} increases sharply at E*=59.3 MeV, due to onset of higher chance (5th) fission as depicted in Fig.4 where the relative fission probability and i-th chance fission time interval τ_{gs}(i), are plotted. The distribution of the average elapsed time τ_{gs} is shown in Fig.5.

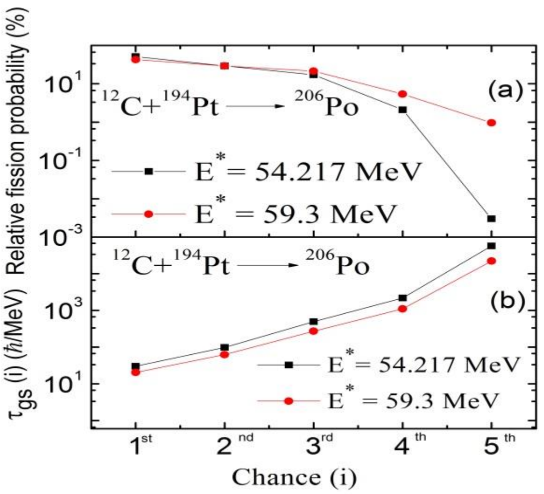

Fig. 4

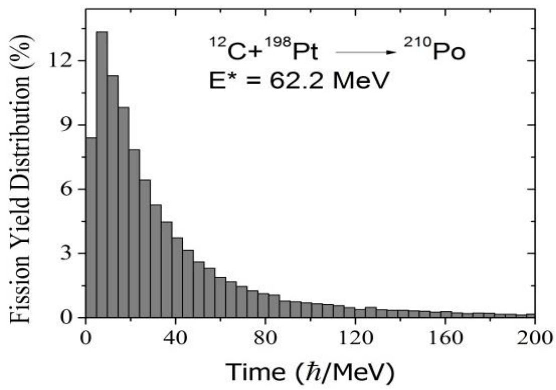

Fig. 5

To conclude, we do not find any shell dependence of β in this work. Further, the fitted values of τ_{ss} are much larger than the usual estimates of saddle to scission transition. Therefore, accounting for experimental n_{pre} remains an open question.

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