Theoretical Calculations of Prescission Neutron Multiplicity for the Polonium Isotopes

Y. Sharma[1],* N.K.Rai[1], and B. R. Behera[1]
[1]*Department of Physics, Panjab University, Chandigarh, India-160014*

Introduction

Bohr hypothesised the theory of compound nucleus in which the projectile and target fuse together to form a fully equilibrated mono-nucleus which decays via various reaction channels.The study of these decays provide an insight into the nuclear structure and the types of nuclear forces involved. It is now well established that the pre-scission neutron multiplicity ($\nu_{\rm pre}$) is one of the most efficient probes to study the nuclear dissipation. Both experimental and theoretical approaches are used to study the dependence of fusion-fission dynamics on factors like shell closure , N/Z ratio, fissility and entrance channel effects.
The motivation behind this work is to reproduce the existing experimental data using theoretical calculations. We use systematics and statistical model calculation to study the effect of N/Z ratio in Po isotopes at similar excitation energy range [1]. Additionally, the trend of $\nu_{\rm pre}$ with excitation energy for ^{206}Po [2] and ^{210}Po [3] is also reported.

Systematics

In our present study, we calculate the pre-scission neutron multiplicity using an empirical formalism [4]. The quantity $\nu_{\rm pre}(A, \tilde{E}^*)$ is expressed as a function of the liquid-drop excitation energy $\tilde{E}^*$, given by:

$$\tilde{E}^* = E^* + \delta W \tag{1}$$

where, δW is the shell correction term. We calculate $\nu_{\rm pre}$ using the following expression,

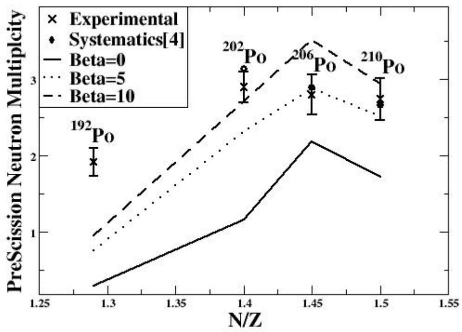

FIG. 1: $\nu_{\rm pre}$ as a function of N/Z.The Po isotopes are populated by ^{48}Ti+^{144}Sm [1], ^{48}Ti+^{154}Sm [1], ^{12}C +^{194} Pt [8], and ^{18}O +^{192} Os $\rightarrow^{210}$ Po [9] at E^* = 72.6 MeV, 72.3 MeV, 76.7 MeV, and 73.5 MeV, respectively. The solid line represents calculations using Bohr-Wheeler fission width.

with an uncertainty of $\Delta\nu_{\rm pre} = \pm 6\%$.

$$\nu_{\rm pre}(A, \tilde{E}^*) = -10.64 + 0.0979A - 0.0154\tilde{E}^* - 0.000234A^2 + 0.000305A\tilde{E}^* \tag{2}$$

Statistical Model Calculations

In the Statistical Model(SM), the fate of compound nucleus at each time step is decided by Monte-Carlo sampling technique. Dissipation factor (β) plays an important role in the decay of a compound nucleus and is therefore used as the only adjustable parameter in our study.β reduces Kramers' fission width up to the saddle point [5], whereas for the saddle to scission point, the time period is modified as follows:

$$\tau_{\rm ss} = \tau_{\rm ss}^{\circ}\sqrt{1 + \left(\frac{\beta}{\omega_{\rm s}^2}\right)} + \frac{\beta}{2\omega_{\rm s}} \tag{3}$$

*Electronic address: sharmayukta314@gmail.com

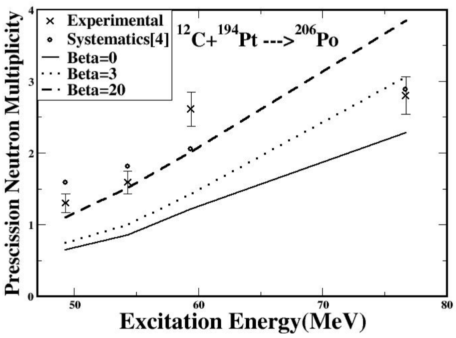

FIG. 2: Systematics and Statistical calculation of ν_{pre} for ^{206}Po. The solid line represents calculations using Bohr-Wheeler fission width.

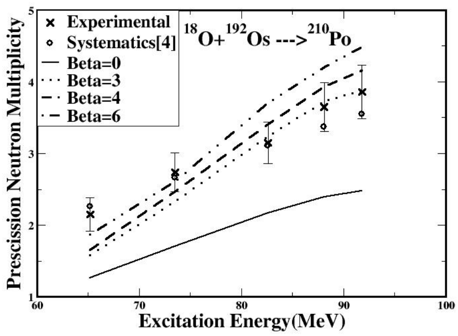

FIG. 3: Systematics and Statistical calculation of ν_{pre} for ^{210}Po. The solid line represents calculations using Bohr-Wheeler fission width.

Coupled channel calculations are performed using CCFULL at each energy points [6] to obtain the required spin distribution, which is then used as an input for the SM code VECSTAT [7]. The evolution of compound nuclei is simulated using this method to reproduce the experimental data, v_{pre} in our case.

Results and Discussions

For the present work, we have investigated the effect of the N/Z ratio on the nuclear dissipation parameter for Po isotopes. It is evident from Fig. 1 that as we go to higher N/Z values, ν_{pre} increases. We observe an anomalous behavior for ^{206}Po, which can be attributed to both the shell closure for ^{210}Po and the entrance channel effect, i.e. $\alpha > \alpha_{\mathrm{BG}}$ for ^{206}Po. SM calculations show that a higher value of β is required for ^{192}Po and ^{202}Po.

Additionally, we study the effect of ν_{pre} with excitation energy for ^{206}Po and ^{210}Po (Fig. 2 and Fig. 3, respectively). Higher values of β are required for ^{206}Po, attributed to the entrance channel effect. Whereas, for ^{210}Po, $\beta = (3-6) \times 10^{21}\ \mathrm{s}^{-1}$ is able to fit the experimental data. We also observe that the systematics calculations are unable to fit all the experimental points.

Therefore, in future studies, the role of the entrance channel effect must be incorporated into both the theoretical models[4][7]. This will enhance our understanding of fusion-fission dynamics.

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