Fission fragment timescales from two-dimensional Langevin dynamical model

M. T. Senthil Kannan[1,2] and Jhilam Sadhukhan[1,2]
[1] *Physics group, Variable Energy Cyclotron Center,*
1/AF, Bidhannagar, Kolkata-700064, India. and
[2] *Homi Bhabha National Institute, Anushakti Nagar, Mumbai-400094, India.*

Introduction

Nuclear fission is the most intriguing research field and challenging due to the involvement of many-body quantum dynamics. Such a large-scale dynamical evolution can be understood by studying observables like prescission particle multiplicities, fission lifetime (τ_f), fission fragment mass and kinetic energy distributions [1–4], etc. Considerable efforts have been given to precisely measure τ_f and the neutron multiplicity (ν_{pre}) [1, 2] over wide ranges of excitation energy and nuclear species. Conventionally, ν_{pre} is often used as a clock to estimate τ_f by invoking the condition: $\tau_f \equiv \tau_\nu^f = \nu_{pre}\tau_\nu$, where τ_ν is the average neutron-decay time usually obtained from a model. Alternatively, neutron clock can be defined as $\tau_{\nu l}^f$ indicating the time when the last neutron is emitted before scission. Both τ_ν^f and $\tau_{\nu l}^f$ reveal fission to be a fast process with a maximum lifetime of 10^{-20}s [1]. However, *atomic probes* the like crystal blocking technique and the K X-ray lifetime measurement infer a much longer scission time (10^{-18}s $\equiv$ 1as) [5]. Very recently, a one-dimensional Langevin dynamical calculation with appropriate shell corrections showed that the average fission lifetime may become long enough as a fraction of fission events may survive more than 10as. To this end, correlation between fission fragment masses and the corresponding τ_f is yet to be studied. A two-dimensional (2D) Langevin dynamical model with temperature-dependent shell corrections is developed and used here to understand such correlations and the corresponding fission fragment mass distributions.

Theoretical Formalism

In the Langevin dynamical model, the nuclear fission dynamics is determined by the interplay between the collective driving force due to change in nuclear shape (collective degrees of freedom) and the stochastic random force of the intrinsic nucleonic degrees of freedom. The Funny-Hill collective/shape coordinates c (elongation) and α (mass asymmetry) are used in the present work to follow the time evolution of an excited nucleus with the 2D Langevin equations. Detailed description of the Langevin equations and the numerical procedure for solving equations are given in [1]. In this work, the reduced dissipation tensor β_{ij} ($= \frac{\eta_{ij}}{m_{ij}}$) is considered as a free parameter to tune ν_{pre} with the measured data. Weisskopf's statistical prescription is used to calculate the evaporation widths of light particles, and Monte-Carlo sampling has been done to check for these decay channels at each timestep [1]. Because of the stochastic nature of Langevin equations, we sample an ensemble of large fission events (2×10^5). For each event, time evolution is followed dynamically up to 10^{-16}s with a time-step of 10^{-25}s. A Langevin trajectory is considered as a fission event when scission criterion $c_s = 0.3R_0$ (R_0 being the spherical radius) is reached [1]. Finally, fission fragment mass yield, ν_{pre}, τ_ν, $\tau_{\nu l}^f$, and τ_f are extracted from the ensemble of events.

Results and Discussions

We considered $^1H + {}^{238}U$ reaction as a representative reaction where experimental ν_{pre} are available for a wide range of energy [2]. We adjust β_{ij} to get a good overall fit with the experimental ν_{pre}. The same β_{ij}s are used to calculate mass distributions for all E^* and

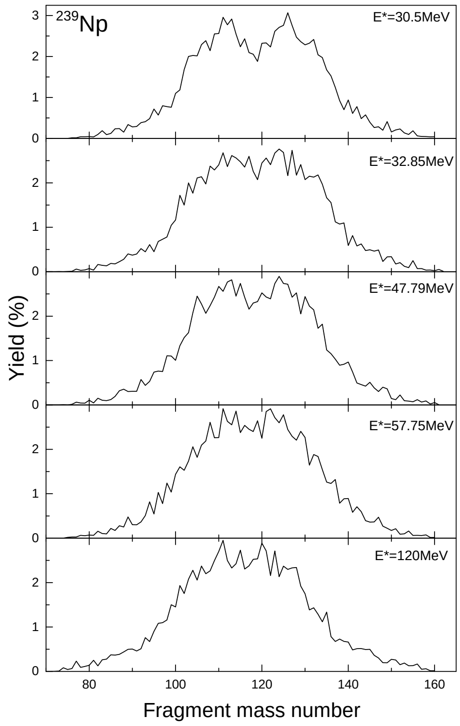

FIG. 1: Evolution of asymmetric to symmetric mass distributions of ^{239}Np for different excitation energies.

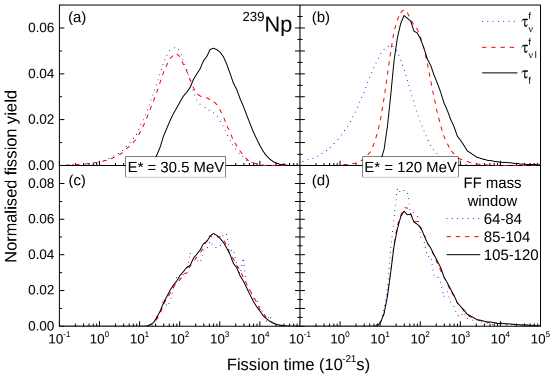

FIG. 2: (a) & (b) The normalised fission yields for ^{239}Np with $E^* = 30.5$ and 120 MeV. (c) & (d) The normalised fission fragment yields are depicted for three different fission fragment groups.

shown in Fig. 1 as a function of fragment mass numbers. We can see the change over from asymmetric to symmetric mass distributions at around 47.79 MeV which is compatible with experimental finding in [6]. Fission fragment mass distributions have larger numerical fluctuations due to low statistics. Further, normalised fission yields for the lowest and the highest E^* are plotted as a function of τ_f, τ_ν^f, and $\tau_{\nu l}^f$ in Fig. 2(a) & 2(b). The distribution corresponding to τ_f has a peak near 10^{-18}s for the lower E^* (Fig. 2(a), and it is considerably shifted from the other two distributions associated to τ_ν^f and $\tau_{\nu l}^f$. It points out the fact that a compound nucleus may survive for a long time without evaporating any neutron. For the higher E^*, this difference reduces as scission occurs much faster. Hence, the distribution corresponding to τ_f (solid lines in Fig. 2b) shifts towards lower fission time. Further, to study the correlation between fission fragment masses and τ_f, we grouped fragment masses into three bins (1) $105 \le A \le 120$, (2) $85 \le A \le 104$, and (3) $64 \le A \le 84$. Fission events and the corresponding τ_f are recorded and normalised for each bin. Eventually, yields are plotted in Fig. 2 (c) & 2(d) for all the three bins, and, as evident, hardly any difference can be observed among these three groups. It interprets that the fission time is primarily decided within the potential pocket around the ground state configuration, which is common to all the different mass combinations. Whereas, fragment masses develops close to the scission region.

References

[1] P. Fröbrich and I. I. Gontchar, Phys. Rep. **292**, 131 (1998).

[2] E. Cheifetz, *et al.*, Phys. Rev. C **2**, 256 (1970).

[3] J. Sadhukhan and S. Pal, Phys. Rev. C **84**, 044610 (2011).

[4] M. T. Senthil Kannan, J. Sadhukhan,*et al.*, Phys. Rev. C **98**, 021601 (2018).

[5] M. O. Frégeau, *et al.*, Phys. Rev. Lett. **108**, 122701 (2012).

[6] A. Chaudhuri, *et al.*, Phys. Rev. C **91**, 044620 (2015).