Entrance channel systematics of fission timescale

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Introduction

It has been observed that the experimental prescission neutron multiplicity (ν_{pre}) were excess over the predictions of Bohr Wheeler model [1]. This has been attributed to the dynamical delay or dissipation in fission in most of the existing works. Strong entrance channel dependence was also observed in the prescission neutron emission. It is generally observed that ν_{pre} values are larger for more symmetric reaction compared with asymmetric reaction forming the same CN [2]. This observation was attributed with the entrance channel spin distribution. However a reverse trend has also been observed in a few cases [3, 4], where the experimental ν_{pre} is observed to be larger for the asymmetric systems compared with the symmetric case. Even though several systematic studies have been conducted, a common systematics could not be achieved for the ν_{pre} data. Saxena *et al.*, [5] reported an entrance channel dependence on fission timescale due to the delay in the formation phase of compound nucleus (CN) in fusion-fission process. However the systematics in Ref. [6] could not observe any significant entrance channel dependence in fission timescale.

In this contribution, we report the statistical model [7] analysis of 26 systems, whose measured ν_{pre} values are reported in the literature. Different reactions considered in this work populate same or similar CN through different entrance channels and cover a fissility range of 0.64 to 0.83.

Analysis and Results

Fission is considered as a delayed process and delays are introduced in each phase of the evolution of the composite system. Diffusion from the equilibrium configuration to the saddle point requires a finite transient time, which is termed as transient delay t_d. The delay t_d results in more ν_{pre} as the CN gets more time to stay in the presaddle stage. A second contribution for the excess emission of neutron is due to the delay in dynamical evolution during the saddle to scission configuration. This delay is termed as t_{ssc}. Thus the total fission timescale is

$$t_{fiss} = t_{stat} + t_{delay} = t_{stat} + t_d + t_{ssc}, \qquad (1)$$

where t_{stat} is the Bohr-Wheeler timescale. In this analysis, we have labelled the data according to the reduced mass asymmetry, r defined as the ratio of the entrance channel mass asymmetry (α) to α_{BG}

$$r = \alpha/\alpha_{BG}. \qquad (2)$$

Deformation dependent level density parameter of Tōke and Swiatecki [8] has been used in this work. Fission barrier is obtained from the rotating finite range model (RFRM) [9] without any scaling. The value of (a_f/a_n) of level density parameters at saddle and ground state deformations are fixed by reproducing the experimental evaporaion residue/fission cross sections. Fusion cross sections are deduced using the expression

$$\sigma_{fus} = \frac{\pi}{k^2} \sum_l \frac{(2l+1)}{1+\exp\left[(l-l_c)/\delta\right]}. \qquad (3)$$

The transient delay t_d is assumed to be fixed (10 zs, 1 zs = 10^{-21}s) following the systematics in Ref. [5] and from the theoretical prediction [10]. t_{ssc} has been varied to fit the experimental ν_{pre} data for all the reactions considered in this analysis.

The fission delay deduced for the systems considered are plotted against the CN fissility in FIG.1. The effect of entrance channel on fission delay is a significant observation in this work. The data systematically fall into two distinct groups according to the entrance channel mass

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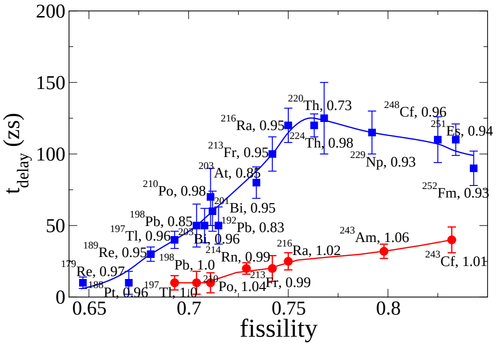

FIG. 1: The fission delay as a function of CN fissility for all the systems considered in this analysis. The CN formed in reactions and the corresponding reduced mass asymmetry are indicated near each data point

asymmetry. The two curves show systematic increase of t_{delay} with fissility. Another observation is the absence of reverse trend in fission delay as other wise observed in the case of ν_{pre}.

In order to explore the origin of reversal in ν_{pre} and not in the fission delay, we have examined the sensitivity of the estimated fission delay on the CN angular momentum. Even though the CN can be populated with the same E* through different entrance channels, the $< l >$ populated may not be the same in all cases. As fission barrier decreases with increase in angular momentum, larger angular momentum would result in higher fission probability in each step of neutron emission. The sensitivity of $< l >$ on fission delay has been observed through simulation of deexcitation of the CN ^{213}Fr at E*=65 MeV. The delay required to reproduce the value of ν_{pre}=3.0 as a function of $< l >$ is shown in FIG.2. It may be noticed that, t_{delay} need to reproduce the ν_{pre} is increasing with larger value of $< l >$.

Though a major part of the difference in t_{delay} observed between systems with $r < 1$ and $r > 1$ populating the same CN could be attributed to formation time [5], the enhanced dissipation effects at higher angular momentum [11] may also be playing a role in the observation.

Summary

The systematic behaviour of the deduced fission timescales for different systems studied [12] shows a clear evidence of influence of entrance channel properties on fission timescale. Eventhough ν_{pre} values show the reverse trend with entrance channel mass asymmetry, the extracted fission delay does not show such a trend in any case. This has been tested to be due to the different $< l >$ values populated in different reactions. Larger fission delays observed in some cases hint the role of angular momentum assisted dissipation. Present analysis calls for the measurement of ν_{pre} for more systems populating same CN through different entrance channel.

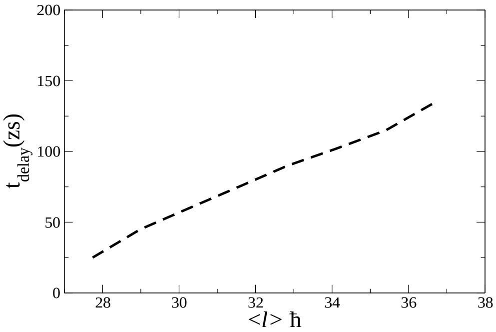

FIG. 2: The fission delay required to reproduce ν_{pre}=3.0 for the CN ^{213}Fr at E*=65 MeV as a function of $< l >$

Acknowledgments

One of the authors (M S) is thankful to KSCSTE for financial assistance in the form of fellowship.

References

[1] N. Bohr and J. A. Wheeler, Phys. Rev. **56**, 426 (1939).
[2] Hardev Singh *et al.*, Phys. Rev. C **78**, 024609 (2008).
[3] J. O. Newton *et al.*, Nucl. Phys. A **483**, 126 (1988).
[4] Varinderjith Singh *et al.*, Phys. Rev. C **86**, 014609 (2012).
[5] A. Saxena *et al.*, Phys. Rev. C **49**, 932 (1994).
[6] Hiroshi Baba *et al.*, Jour. Phy. Soc. Japan **66**, 998 (1997).
[7] J. P. Lestone, Phys. Rev. Lett. **70**, 2245 (1993).
[8] J. Töke and W. J. Swiatecki, Nucl. Phys. A **372**, 141 (1981).
[9] Arnold J. Sierk, Phys. Rev. C **33**, 2039 (1986).
[10] K. H. Bhatt *et al.*, Phys. Rev. C **33**, 954 (1986).
[11] W. Ye, Phys. Rev. C **76**, 041601 (2007).
[12] M. Shareef *et al.*, Submitted to Eur. Phys. J. A(2016).