Sensitivity of Prefission Neutron Multiplicity to Fission Time Measurement at Low Excitation Energy

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Introduction

A recent work [1] using a dynamical fission model has claimed to have solved the long-standing puzzle of very long fission times (~10^{-18} s) measured by the atomic techniques compared to much shorter corresponding fission delays measured by prefission neutron multiplicity (ν_{pre}) technique. The argument given [1] is the usual one [2], namely lack of sensitivity of prefission neutron multiplicities to long fission timescales. In an earlier work [3], we showed that the lack of sensitivity arises only when the neutron clock saturates that is the excitation energy of the fissioning nucleus goes below neutron emission threshold by multiple neutron emission. It has been claimed [1] that prefission neutron emission takes place quite early (~10^{-19} s) and reaches saturation level as the available excitation energy falls below neutron threshold for ^{224}Th produced at a relatively low excitation energy (E_X=36 MeV) by ^{16}O+^{208}Pb reaction. On the other hand, the fissioning system survives for a long time (~10^{-18} s) and hence the prefission neutron multiplicity (ν_{pre}) is not sensitive to fission time (~10^{-18} s). At high excitation energy, ref [1] predicted that both atomic and ν_{pre} techniques would give very short fission time, although it is known [4,5] that the puzzle exists even at E_X = 200 MeV and also for quasifission reactions [6].

In the present paper, we restrict ourselves to a discussion of the sensitivity of prefission neutron multiplicity to the determination of fission delays and the dependence of evaporation residues on the pre-saddle and post-saddle delays for ^{16}O+^{208}Pb reaction at E_{Lab}(^{16}O)=88.9 MeV producing ^{224}Th at a relatively low excitation energy (E_X=36 MeV). We find that ν_{pre} is sensitive to both pre-saddle and post-saddle fission delays in 10^{-18} s–10^{-17} s timescale at this low excitation energy. We start with a discussion of the standard method used [4] to determine fission delay from the measured ν_{pre} and its limitations.

Nuclear Experimental Technique

The neutrons are detected in coincidence with the fission fragments and the prefission neutrons are separated from postfission neutrons by kinematical techniques. In the case of ^{16}O+^{208}Pb reaction producing ^{224}Th (E_X=36 MeV), measured prefission neutron multiplicity (ν_{pre}) is 1.9±0.2, whereas, statistical ν_{pre} due to the statistical fission process as obtained from any standard statistical model is ≈0.45. Hence clearly, the fission is delayed beyond the statistical fission time. It requires a dynamical model to understand whether the delay is in the pre-saddle state or post-saddle state of the fissioning nucleus. However, it is clear that the majority of the prefission neutrons are emitted due to either pre-saddle or post-saddle delay or a combination of the two delays. Since, the neutron emission is a statistical process, it should be possible to determine the fission delay from the measured ν_{pre} in the framework of a modified statistical model [7] and this approach has been generally used by the experimentalists. The technique loses its sensitivity [3] as ν_{pre} reaches its saturation value. The saturation of ν_{pre} does not depend on the details of fission dynamics and could be studied in a modified statistical model [7] by simply introducing either a pre-saddle or post-saddle delay. So, the conclusion about the sensitivity of ν_{pre} to fission delay as obtained from a static model like JOANNE2 [7] should not change when a dynamical model is used.

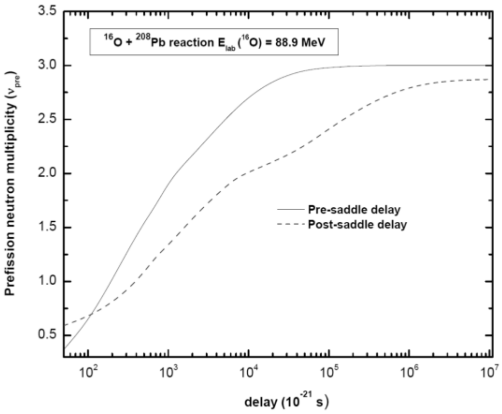

Fig.1: Calculated ν_{pre} versus pre-saddle delay (solid line) and post-saddle delay (dashed line).

Results

Following the results of Langevin dynamical model calculations [1,2], let us first assume that the fissioning nucleus spends most of its time in pre-saddle state without any significant deformation. Statistical neutron emission calculations have been carried out accordingly with only a pre-saddle delay without any deformation of the fissioning nucleus. In Fig. 1, we show a plot of pre-saddle delay versus ν_{pre} for $^{16}O+^{208}Pb$ reaction producing ^{224}Th (E_X=36 MeV). The measured ν_{pre}=1.9 implies a pre-saddle delay =1×10^{-18} s and clearly ν_{pre} is sensitive to pre-saddle delay in 10^{-18}-10^{-17} s timescale. The saturation value of ν_{pre} is =3 and the neutron clock becomes insensitive to pre-saddle delay in 10^{-16} s timescale. However, a long pre-saddle delay (~10^{-18} s) overestimates evaporation residue cross-section (σ_{ER}) by a factor of >5 (compared to measured σ_{ER}) and such a large increase in σ_{ER} cannot be compensated by any reasonable increase of a_f/a_n (ratio of level density parameters at saddle to equilibrium shape). Fröbrich and Gontchar [8] also obtained gross overestimation of σ_{ER} for long pre-saddle delay in their dynamical model.

In Fig. 1, we show by dashed curve, post-saddle delay versus prefission neutron multiplicity (ν_{pre}) assuming a deformation energy =7.45 MeV. The measured ν_{pre}=1.9 gives a post-saddle delay=6×10^{-18} s. Prefission neutron multiplicity (ν_{pre}) is sensitive to post-saddle delay in 10^{-18}-10^{-16} s timescale and saturates to ≈3 in 10^{-15} s timescale. In this case, the calculations can reproduce measured σ_{ER}.

Conclusion

Contrary to the conclusion of ref. [1], ν_{pre} is sensitive to fission delays in 10^{-18}-10^{-17} s timescale at low E_X for $^{16}O+^{208}Pb$ reaction and the measured ν_{pre} values give fission delays on the order of 10^{-18} s, in agreement with the dynamical calculations[1]. However, a long pre-saddle delay[1,2] grossly overestimates measured σ_{ER} and hence a long post-saddle delay appears more reasonable. Moreover, $^{16}O+^{208}Pb$ is not a satisfactory system for testing the dynamical model [1], because there are no atomic probe results for this system. In conclusion, we do not expect any significant anomaly in fission time measurement using nuclear technique versus atomic probes at low excitation energies. The nuclear fission time puzzle primarily exists at high excitation energies and for quasifission reactions that ref. [1] did not address.

Amlan Ray acknowledges financial assistance from Science and Engineering Research Board, Government of India, grant no: EMR/2016/001914.

References

[1] M. T. Senthil Kannan *et al.*, Phys. Rev. C **98**, 021601 (R) (2018).
[2] D. Jacquet, M. Morjean, Prog. Part. And Nucl. Phys. **63**, 155 (2009).
[3] A. K. Sikdar *et al.*, Phys. Rev. C **93**, 041604 (R)(2016).
[4]D. J. Hinde *et al.*, Phys. Rev. C **45**, 1229 (1992).
[5] F. Goldenbaum *et al.*, Phys. Rev. Lett. **82**, 5012 (1999).
[6] R. du Rietz *et al.*, Phys. Rev. Lett. **106**, 052701 (2011).
[7] J. P. Lestone, Phys. Rev. Lett., **70**, 2245 (1993).
[8] P. Fröbrich, L. L. Gontchar, Phys. Rep. 292, 131 (1998).