# Investigating the effect of shell closure on fusion-fission dynamics by estimating the fission delay

Rupinder Kaur[1], Maninder Kaur[1], BirBikram Singh[2], and Varinderjit Singh[1*]
[1]Department of Physical Sciences, I.K. Gujral Punjab Technical University, Kapurthala – 144603, INDIA
[2]Deptartment of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib – 140406, INDIA
* email: mangat_phy@yahoo.co.in

## Introduction

Current interest in nuclear physics research is the synthesis of super heavy elements (SHE). Attempts to achieve the theoretical predicted island of stability are in progress. The theoretically predicted stability of SHE is due to the presence of shell closure in these nuclei. Different theoretical models predict different numbers for the next neutron and proton shell closure after 126 and 82, respectively. The understanding about the effect of existing shell closure on fusion dynamics is necessary to achieve the next shell closure which will contribute to the production of SHE and will provide an important insight into the determination of an island of stability

The effect of shell closure on fusion dynamics has been investigated by several authors using different probes. It has been very well established that pre-scission neutron multiplicity can act as a neutron clock to evaluate the time scales of the fusion-fission process. The delay in the fusion-fission process, if any, and its variation with the shell closure can provide information about the importance of shell closure on fusion dynamics. Further, the simultaneous analysis of the experimental Evaporation Residue (ER) cross-sections and neutron multiplicity in the same framework will provide a consistent picture of fusion dynamics. In the present work, we present the simultaneous analysis of neutron multiplicity and ER cross-sections to understand the effect of shell closure on fusion dynamics for $^{19}F+^{198}Pt \rightarrow ^{217}Fr$ (N=130) and $^{19}F+^{194}Pt \rightarrow ^{213}Fr$ (N=126).

## Theoretical Calculations

The experimental neutron multiplicity and ER cross-sections have been obtained from the work of Singh *et al.* [1-2]. The theoretical data has been analyzed using the statistical model based code Joanne2 [3]. In this code, the pre-saddle particle decay widths and fission widths are calculated using rotating finite range model (RFRM), the deformation and rotational energies using Liquid drop model (LDM) and particle binding energies and transmission coefficients are obtained using optical model potential.

## Results

The experimental ER cross-sections for both the systems were fitted by varying the value of scaling factor for the fission barrier, $k_f$. It was observed that the ER cross-sections for both the systems were reasonably fitted by using $k_f$ =1.17 in the calculations. Figure 1 shows the comparison of experimental cross-sections (solid points) and theoretical cross-sections (lines). The pre-scission neutron multiplicity was fitted by varying the delay time (both transient time ($\tau_{tr}$) and saddle to scission time ($\tau_{ssc}$)) and using $k_f$ =1.17. The errors in the delay time is estimated using the errors in the experimental results. It has been observed that theoretical neutron multiplicity depends on the total delay (= $\tau_{tr}$ + $\tau_{ssc}$) and is insensitive to the distribution of the delays. Figure 2 shows the variation of the total time delay required to fit the neutron multiplicity as a function of excitation energy for $^{217}Fr$ (solid line) and $^{213}Fr$ (dotted line). Evidently the statistical model calculations under-predicted the experimental neutron multiplicities for all excitation energies except the lowest two excitation energies for $^{213}Fr$ (shell closed compound nucleus (CN)). So, the total delay time was varied to explain the experimental neutron multiplicity. It is observed that the excitation energy dependent delay is required to explain the experimental results for both the CN.

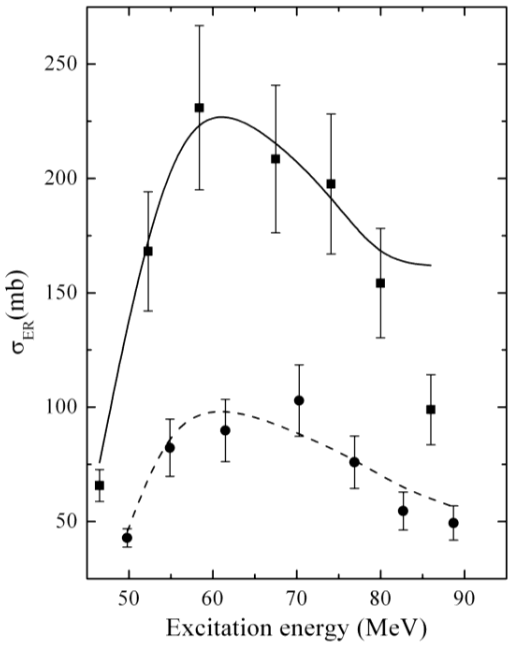


**Fig. 1** Comparison of experimental ER cross-sections ($^{217}$Fr (solid squares) and $^{213}$Fr (solid circles)) and theoretical calculations ($^{217}$Fr (solid line) and $^{213}$Fr (dotted line)) at $k_f$ = 1.17 for both the systems.

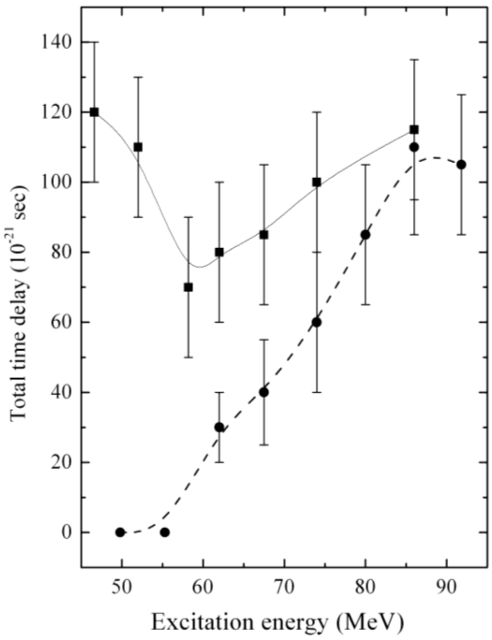


**Fig. 2** Comparison of total time delay required to fit the pre-scission neutron multiplicities $^{217}$Fr (Solid squares and solid line) and 213Fr (Solid circle and dotted line).

## Conclusions

The comparison of the fission delay for both the system under consideration indicates that the delay is less for shell closed CN in comparison to the non-shell closed CN. The difference in the delay time is maximum at lowest excitation energy studied and delay time for both systems approaches each other as one moves from low to high excitation energy. This observation may be attribute to the washing out of the effect of shell closure with increase in the excitation energy. Also, this observation indicates that the shell closure does not provide any extra stability to CN against the fission delay, which was predicted by theoretical models. This present work is also consistent our earlier observation [2].

## Acknowledgement

One of the author (RK) would like to thank the financial assistant provided in terms of the junior research fellowship received from the IUAC research project.

## References

[1] V. Singh *et al.* Phys. Rev. C **86**, 014609 (2012).
[2] V. Singh *et al.* Phys. Rev. C **89**, 024609 (2014).
[3] J. P. Lestone Phys. Rev. Lett. **70**, 2245 (1993).