# Effect of shell closure on nuclear dissipation at high excitation energy using neutron multiplicity as a probe

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## Introduction:

In the last few decades much progress has been made to understand the behavior of nuclear matter at finite temperatures (say between 1 and 5 MeV) using both experimental and theoretical techniques . Nuclear fission is one of the most interesting processes, to study the behavior of nuclear matter, as it involves the large scale collective nuclear motion, and is dynamical in nature. Kramers has incorporated the dynamical nature of fission and introduced the concept of nuclear viscosity or dissipation [1]. Experimental signatures for this dissipation are observed through large excess in pre-fission neutrons, gamma ray multiplicities from the compound nucleus giant dipole resonance (GDR), light charged particles and evaporation residues in comparison to standard statistical model, for the heavy ion induced fusion-fission or fusion evaporation reactions. From the analysis of large set of experimental data [2] it is well established that there exists a large dissipation at nuclear temperature between 1 and 2 MeV.

In the literature several studies exists, which shows the effect of shell closure on fission anisotropy, level density, fusion cross-sections etc. It has been observed that the shell closed compound nucleus (CN) behave quite differently in comparison to non shell closed CN. There exists only one measurement carried out by Back et al. [3] to study the effect of shell closure on the nuclear dissipation through evaporation residue measurement. To understand the effect of shell closure on nuclear dissipation more clearly, we have measured the pre-scission neutron multiplicity ($\nu_{pre}$) for $^{19}$F + $^{194,196,198}$Pt systems resulting in the formation of the CN $^{213}$Fr ($N_c$=126), $^{215}$Fr ($N_c$=128) and $^{217}$Fr ($N_c$ = 130) systems at excitation energy range of 45 – 91.8 MeV.

## Experimental Arrangement:

The experiment was performed using 15UD pelletron + LINAC and National array of Neutron Detectors (NAND) facilities at IUAC, New Delhi. Pulsed beam of $^{19}$F (Energy Range = 90 – 140.8 MeV) at repetition rate of 250 ns with pulse width of 0.8 ns was bombarded on the targets of $^{194}$Pt, $^{196}$Pt and $^{198}$Pt and the neutrons emitted from the compound nucleus were detected in coincidence with fission fragments [4].

## Experimental Results and Theoretical Calculations:

The raw neutron TOF spectra were converted to energy spectra for all the detectors. These energy spectra have contribution from neutrons originated from three different sources (compound nucleus evaporation and two fission fragments). The total neutron multiplicity $\nu_{total} = \nu_{pre} + 2 * \nu_{post}$. In order to obtain the pre-scission and post-scission contributions, energy spectra of all detectors are fitted simultaneously using chi-square minimization process, for different neutron-fission angle combinations, with Watt expression[4]. Pre-scission neutron multiplicities thus obtained by the above fitting procedure for the decay of $^{213}$Fr, $^{215}$Fr and $^{217}$Fr at different excitation energies are shown in Fig. 1.

In the standard statistical model calculations along with fission, emission of neutrons, protons alphas and giant dipole resonance (GDR) γ-rays are also considered as possible decay channels of compound nucleus. The light particles and the

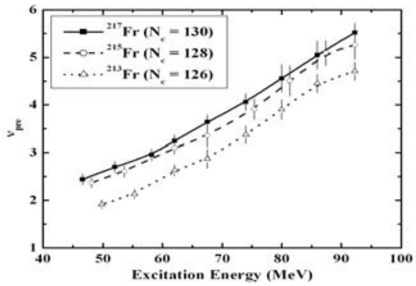


Fig. 1: Variation of $\nu_{pre}$ with excitation energy for different systems. Lines are only to guide the eye.

GDR partial width has been obtained by using the Weisskopf formula [5]. The Bohr-Wheeler fission width has been calculated from the transition-state model as phase integral over all the available states at the saddle point [6]. The level density parameter is taken from the work of Ignatyuk et al. [7] who proposed a form, which takes into account the nuclear shell structure effect at low excitation energies.

In the statistical model calculations the dissipative dynamical effect of nuclear fission was incorporated using the time dependent Kramer modified Bohr-Wheeler expression for fission width as [1]

$$\Gamma_K = \frac{\hbar \omega_{gs}}{T} f_\beta \Gamma_{BW} \quad ....(1)$$

Where

$$f_\beta = \sqrt{1 + \left(\frac{\beta}{2\omega_{sad}}\right)^2} - \frac{\beta}{2\omega_{sad}}$$

Where $\Gamma_{BW}$ is the Bohr-Wheeler fission width, β is the reduced dissipation coefficient, $\omega_{gs}$ and $\omega_{sad}$ are the local frequencies of the harmonic oscillator potentials which osculate the liquid drop model nuclear potential at ground state and saddle configuration, respectively. Transient and saddle to scission times are also taken into account [8].

In the calculation the experimental $\nu_{pre}$ are fitted by varying the temperature dependent reduced dissipation strength (β) coefficient for the three compound nuclei. Fig. 2 shows the comparison of β for the different CN ($^{217}$Fr, $^{215}$Fr and $^{213}$Fr).

## Discussion:

Experimental Pre-scission neutron multiplicities have been compared with the statistical model predictions as mentioned above. It has been observed that the statistical model prediction underestimate the experimental pre-

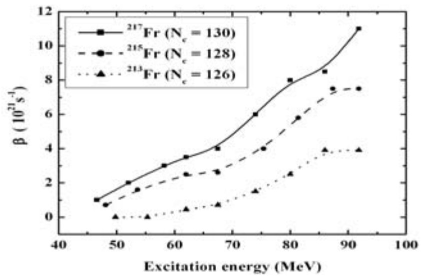


Fig. 2: Comparison of the reduced dissipation coefficient (β) required to reproduce experimental obtained pre-scission neutron multiplicities for $^{217}$Fr (square), $^{215}$Fr (circle) and $^{213}$Fr (triangle) compound nucleus.

scission neutron multiplicities. It is also observed that the Bohr-Wheeler predicted $\nu_{pre}$ decreases with the excitation energy, whereas the experimental value increases with the excitation energy. This clearly shows the signature of the dissipation in the fusion-fission dynamics.

Experimental $\nu_{pre}$ decreases as we move from compound nuclei $^{217}$Fr ($N_c$ = 130) to $^{213}$Fr ($N_c$ =126) through $^{215}$Fr ($N_c$ = 128) (Fig. 1) . At the similar excitation energy the change in $\nu_{pre}$ is less as we go from $N_c$ = 130 to 128 in comparison to the change in case of $N_c$ = 128 to 126. The comparison of the experimental results with the statistical model prediction shows that the deviation from the predicted values occurs at a higher excitation energy for $^{213}$Fr ($N_c$ = 126) shell closed compound nucleus, whereas such deviation are visible at much low excitation energies for the other two compound nuclei. The comparison of the reduced dissipation strength (β) for different systems (Fig. 2) shows that dissipation is quite less in case of shell closed compound nucleus ($^{213}$Fr) compared to the other compound nuclei. The higher threshold excitation energy for the onset of dissipation and low reduced dissipation strength for shell closed compound nucleus perhaps indicate that there may be some effect of shell structure which is responsible for these observations. However, it need further theoretical investigation.

**References**


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