Search for an effect of shell closure and role of N/Z on nuclear dissipation via neutron-multiplicity measurements

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Dissipation phenomena are well known in the dynamics of macroscopic systems. Evidence for dissipation in strongly interacting systems like nucleus has been accumulated for large number of studies of nuclear dynamics at temperatures of the order of a few MeV in the past [1-2]. Recently dissipative dynamics is also found to play a crucial role in the evolution of matter at extremely high densities and temperatures created in collisions between two heavy nuclei at ultra relativistic energies [3]. In another recent paper Auerbech and Sholomo [4] pointed out that the strength of the dissipation-to-entropy density ratios obtained from nuclear systems at low as well as very high temperature are very similar. Exploring dissipation phenomena is one of the challenges in present day nuclear physics.

Dissipation in nuclear dynamics in the mean-field regime accounts for the coupling of the collective motion with the intrinsic nucleon degrees of freedom. The energy spectrum of intrinsic motion has a well-defined shell structure on the strength of nuclear dissipation. In particular, a scan of nuclear dissipation across the neighborhood of a closed shell nucleus can reveal the effect of shell closure [5].

Nuclear dissipation manifests itself in heavy-ion-induced fusion-fission reactions through the enhancement of pre-scission evaporation of neutrons, other light particles and photons with respect to the predictions of the standard statistical model of compound nuclear decay. An enhancement of the evaporation residue cross section is also observed. Dissipation hinders or slows down the fission process, causing an increase in the number of evaporated particles and γ- rays prior to fission [8]. In the statistical model the strength of the nuclear dissipation is treated as a free parameter and its value is obtained from fitting of experimental data. The dissipation strength thus obtained experimentally depends on the magnitude of other nuclear properties like the separation energy, the level density and the fission barrier used in the statistical model calculation. One may like to know to what extent the shell corrections in the above nuclear properties affect the fitted values of the dissipation strength. A proper understanding of such issues is important in order to attribute the value of the best-fit dissipation parameter to the true dissipative property of the compound nucleus. Furthermore, any shell effect in dissipation is expected to be revealed in its best-fit values when shell corrections in all the other nuclear properties are accounted for in the statistical model calculations.

In another aspect it is also of considerable interest to explore the effect of N/Z in compound nuclei for a given element on the strength of nuclear dissipation. Measurement of pre-scission neutron multiplicities from an isotopic chain will be a suitable tool for the above purpose [6-7].

The exact determination of fission barrier height is essential to understand the dynamics of the fusion-fission process and the prediction of super heavy elements. The attempt to extract shell correction to the fission barrier from the experimental fission barrier from the fission data in heavy ion-induced fusion-fission reaction is rather scarce. In few of the recent studies it is shown that inclusion of neutron multiplicity data along with fission and Evaporation residue data, and its simultaneous fitting helps in the extraction of the shell correction energies.

In an attempt to understand few of the above aspects a series of experiments for measuring neutron multiplicities were carried out at the National neutron detector array (NAND) facility of Inter University Accelerator centre (IUAC) Pelletron+LINAC accelerator facilities. Neutron multiplicities were measured for $^{19}F+^{194,196,198}Pt$, $^{16,18}O+^{194,198}Pt$ and $^{12}C+^{194,198}Pt$ systems. Details of these experiments can be found in ref [5-10].

In the pre-scission neutron multiplicity excitation function for compound nuclei $^{213,215,217}Fr$ it was found that the strengths of the reduced dissipation coefficient for nuclei which are away from shell closure are very similar, and it is suppressed for closed shell nuclei at low excitation energy. It is also further demonstrated the importance of using the correct neutron binding energy in the neutron width calculation, in order to extract the dissipation strength from fitting experimental neutron multiplicity. The shell correction in fission barrier, however, does not affect the fitted values of the dissipation coefficient as strongly as is found when including shell effects in nuclear masses or in the level density parameter [5, 8].

The pre-scission neutron multiplicities of the four compound nuclei $^{210,212,214,216}Rn$ having N/Z values as 1.441, 1.465, 1.488, 1.511 respectively populated through $^{16,18}O+^{194,198}Pt$ systems were analyzed treating dissipation strength as an adjustable parameter in the statistical model. It is found that measured pre-scission neutron multiplicities increases with the increase of N/Z of the compound nuclei at all energies except at the lowest one. The N/Z dependence of the dissipation strength at the lowest excitation energy suggests shell closure effect. Such effects are not observed at higher excitation energies where the variation of the dissipation strength with N/Z does not show any trend [6-7].

In the pre-scission neutron multiplicity analysis of $^{12}C+^{194,198}Pt$ (forming non shell-closed ^{206}Po and shell-closed ^{210}Po compound nucleus), it is shown that considerable amount of shell correction at the saddle point is required to fit the measured experimental data [9].

Recently these studies have also been extended taking evaporation residue as a probe [11-12]. The results obtained are also similar to those obtained through neutron multiplicity measurements.

In the present talk, after a brief introduction in various aspects of dissipation phenomena in fusion-fission dynamics, I will mainly focus on the recent results of neutron multiplicity measurements carried out at IUAC Pelletron+LINAC accelerator facility.

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