Saddle point shell correction energies from pre-scission neutron multiplicities

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The significance of nuclear shell structure in the formation of a new element in heavy ion induced nuclear reaction is a problem of current interest. Few attempts have been made recently to understand the role of shell correction energies on the fission threshold as a function of the nuclear deformation. Such studies bring out the interplay of macroscopic properties of nuclear matter to the microscopic effects such as deformation and shell structure of the nuclei. The quantitative determination of fission barrier height is the key to understand the dynamics of heavy ion fusion-fission process and the prediction of the super heavy elements. Many researchers have carried out theoretical calculations for the fusion-fission probability in the super heavy mass region in the frame work of a potential energy landscape in multidimensional deformation space. The existence of the island of stability has also been proposed using the nuclear shell model. However, very few attempts have been carried out to extract the shell correction to the fission barrier from the experimental fission data in heavy ion induced fusion-fission reactions. It has been shown that[1] the shell corrections at saddle point is necessary to explain the measured fission cross-sections, the evaporation residue cross sections and the pre-scission neutron multiplicity data simultaneously in mass ~ 200 region. With this motivation, we have carried out measurements of neutron spectra for $^{12}C+^{194,198}Pt$ systems [2].

The statistical model code PACE2 with modified level density and fission barrier prescription [1] was used to extract the shell correction values from the experimental observables. Energy dependent shell corrections were used to obtain level density parameter at equilibrium ($\tilde{a}_n$) and saddle point ($\tilde{a}_f$)with respective shell corrections. Further details can be found in Ref. [1]. The fission barrier is calculated by adding the shell correction at ground state(Δ_n) and that at saddle point (Δ_f) to the liquid drop component of fission barrier.The Δ_f is assumed to be $k_f \times \Delta_n$ where k_f is determined by fitting the experimental data. The initial J distribution of the decaying compound nuclei are obtained from the fits to the experimental fusion excitation functions using the coupled channel code CCDEF. A simultaneous fitting of all the experimental data available; viz fission and evaporation residue cross sections and pre-scission neutron multiplicities was carried out by varying (k_f, $\tilde{a}_f/\tilde{a}_n$) following the procedure discussed in Ref. [1].

In Fig. 1 the experimental pre-scission neutron multiplicities are compared with the statistical model (SM) predictions for the decay of CN with the modified fission barrier and level density prescription as described above also fitting simultaneously fusion and fission excitation functions. The bottom panels of Fig.1 shows how good the SM calculations (continuous line) using the best fitted (k_f, $\tilde{a}_f/\tilde{a}_n$) parameters match with the experimental fusion (filled diamond) and fission (filled

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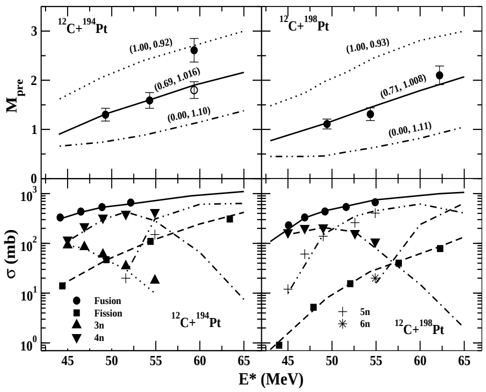

FIG. 1: Experimental pre-scission neutron multiplicities, fusion,fission and ER excitation functions along with the statistical model calculation results.

uptriangle) excitation functions [3]. To understand the effects of shell correction at saddle point satisfying the fission excitation functions, the SM calculations have been carried out with different conditions to estimate the average pre-scission neutron multiplicity. As can be seen from the Fig. 1 the calculated neutron multiplicities without any shell correction at the saddle point (k_f=0.0) underpredict the experimental values. Whereas, the calculated neutron multiplicities with full shell corrections at the saddle point k_f=1.0 (dotted line) overpredict the measured data. As the excitation energy of the fissioning system increases, the dynamical effect comes into picture which eventually increases the number of neutrons emitted before scission. Hence the simultaneous fitting of fusion and fission cross sections and pre-scission neutron multiplicity to obtain the best fitted (k_f, $\tilde{a}_f/\tilde{a}_n$) values was done at the lower two excitation energies. Thus obtained k_f was used to estimate the saddle point shell correction and thereby to determine the fission barrier height. The uncertainties in the fitted parameters are obtained by minimizing the χ^2 and are $\lesssim$ 5% . It is interesting to note that in case of ^{12}C+^{198}Pt system the best fitted value of (k_f, $\tilde{a}_f/\tilde{a}_n$) thus obtained could satisfactorily explain the pre-scission multiplicity at the highest excitation energy also. However it underpredicts the data at the highest energy for ^{12}C+^{194}Pt system. A fission delay of 30× 10^{-21}s was incorporated to estimate the dynamical correction in the pre-scission neutron multiplicity [1]. The data shown in open circle in Fig. 1 is obtained by considering the dynamical effect and it shows that the inclusion of fission delay is essential to satisfactorily explain the measured pre-scission multiplicities at the highest excitation energy for the ^{12}C+^{194}Pt system. However, the incorporation of dissipative effects are not required to explain the experimentally measured pre-scission multiplicities for ^{12}C+^{198}Pt system in the energy domain under consideration. Hence it could be conjectured that dissipation effects are felt for shell closed nuclei only at higher excitation energy compared to nuclei away from closed shell.

To conclude, we have determined the shell correction energies within an uncertainty of 5% at the saddle point by measuring the average pre-scission neutron multiplicities for ^{12}C+^{194}Pt (forming ^{206}Po) and for ^{12}C+^{198}Pt (forming the shell closed compound nucleus ^{210}Po) systems. Combining the neutron multiplicity data with the ER and fission cross section data already measured for these systems, we could tune the statistical model parameters in a global manner by fitting all the measured experimental observables simultaneously. It has been demonstrated that the introduction of shell correction of ∼ 70% at the saddle point potential energies with respect to the ground state shell correction value is crucial for the description of the measured pre-scission neutron multiplicities and the difference in their values for the two systems.

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