Effects of Neutron Shell Closure in Fission Dynamics

Golda K.S.[1,2],* A. Saxena[3] , V.K. Mittal[2], K. Mahata[3], A. Jhingan[1], P. Sugathan[1], V. Singh[4], R. Sandal[4], S. Goyal[5], J. Gehlot[1], A. Dhal[1], B.R. Behera[4], R.K. Bhowmik[1], and S. Kailas[3]

[1]Inter University Accelerator Center, Aruna Asaf Ali Marg, New Delhi – 110067

[2]Department of Physics, Punjabi University, Patiala,Punjab – 147 002.

[3]Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai – 400085

[4] Department of Physics, Panjab University, Chandigarh – 160014

[5]Department of Physics and Astrophysics, University of Delhi – 110007

* email: golda@iuac.ernet.in

The study of fusion-fission dynamics in nucleus-nucleus collision to find optimum conditions for the synthesis of super heavy elements is an exciting topic these days. Some experiments [1] have been carried out to understand the mechanism involved in the heavy ion induced fusion reactions which shows the effects of entrance and exit channel shell closure in the enhancement of fusion cross section. K. Mahata, et.al [2] have tried to explain how the shell corrections at saddle point is helpful in explaining the evaporation residue cross sections and pre-scission neutron multiplicity data in mass ~200 region. In this work we have carried out experiments recently to understand the effects of neutron shell closure in fission dynamics using neutron multiplicity measurements. The measurement of average neutron multiplicity has been extensively used to study the neutron emission as a 'Clock' for establishing the time scale for fusion-fission reactions[3].

The experiment has been carried out to study the effects of shell closure in fusion-fission dynamics using the heavy ion facility at Inter University Accelerator Centre, New Delhi. Pulsed beam of ^{12}C at energies from ~62 MeV to 81MeV delivered by Pelletron, was bombarded on targets of ^{194}Pt and ^{198}Pt of thickness 1.75 mg/cm^2 and 1.45 mg/cm^2 respectively. The beam energies had been so adjusted that the measurements were done at the same excitation energies; 50, 55 and 60 MeVs for both the systems. Fission fragments were detected by a pair of Multi-wire proportional counter (MWPC) (5" $\times$ 3") kept at $\pm$40 degree with respect to beam direction at a distance of 17 cm from target position.

24 neutron detectors (BC501) at different angles around the target chamber were used for the neutron TOF measurements. Out of these 24 detectors, 16 detectors (5" thick $\times$ 5" diameter) were kept in reaction plane and remaining 8 detectors (3" $\times$ 5") were kept at $\mp 16^o$ up and down with respect to the reaction plane. Four of the reaction plane detectors were placed at 1 meter away from the target. All the remaining detectors were placed at 2m away from the target in a cylindrical fashion. In order to reduce gamma background beam dump was extended 4m downstream from target and beam line was shielded with paraffin and lead bricks. The time width of the beam was continuously monitored using a BaF_2 detector placed near to the beam dump and it was found to be between 0.80 to 1.2 nsec at different beam energies. Discrimination between neutrons and γ rays was made by using pulse shape discrimination based on the zero-crossing technique and the TOF. The TOF of neutrons were converted into neutron energy by considering the prompt γ peak in the TOF spectrum for reference time.

The pre- and post-scission components of neutron multiplicities were obtained from the measured neutron energy spectra by using a multiple source least-square fiting procedure, using Watt expression. Three moving sources of neutrons (The CN plus two fully accelerated fission fragments) were considered while determining the multiplicities from the fits. The neutrons emitted from these moving sources were assumed to be isotropic in their respective rest frames. Thus the measured neutron multiplicities are given as

$$\frac{d^2M_n}{dE_n d\Omega_n} = \sum_{i=1}^{3} \frac{M_{n_i}\sqrt{E_n}}{2(\pi T_i)^{3/2}} \exp\left[-\frac{E_n - 2\sqrt{E_n E_i/A_i}\cos\theta_i + E_i/A_i}{T_i}\right]$$

Where A_i, E_i, T_i and M_{ni} are the mass, energy, temperature and multiplicity of each neutron emitting source *i*. E_n is the laboratory energy of neutron and θ_i is the neutron detection angle with respect to the source *i*. Fission fragment velocities and folding angle are obtained from Viola [4] systematics for symmetric fission.

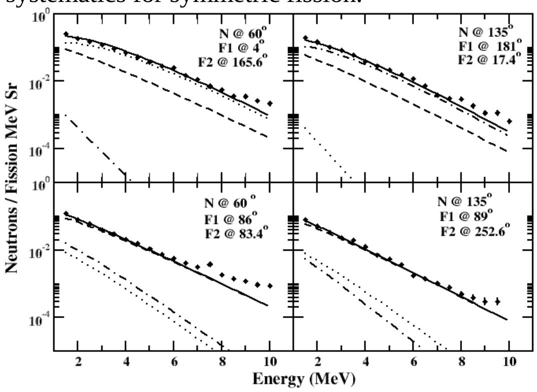

Fig.1 Double differential neutron multiplicity spectra for $^{12}C+^{194}Pt$ at 60MeV excitation energy along with the fits for the pre-scission (dashed curve) and post-scission from one fragment (dotted curve) and that from the other (dot dashed curve). The solid curve represents the total contribution.

The angular acceptance of both the neutron detectors and the fission detectors are taken into account while calculating the relative angle between the neutron and the source direction in the fiting procedure. Fig.1 shows the fits to the double differential neutron multiplicity spectra at various angles for the two reactions. The pre-scission temperature has been calculated by assuming a level density parameter of $A_{CN}/9$ $MeV^{-1}$and was fixed in the moving source fits.

The experimental neutron multiplicities are compared with the statistical model predictions, PACE for the decay of a CN with a modified fission barrier and level density prescription[2]. Fig.2 compares the statistical model calculations with the experimental M_{pre} for both the systems as a function of CN excitation energy. The fission barrier height and the ratio of single particle level density parameters at saddle point to ground state are adjusted to reproduce the fission and ER cross sections measured earlier. A shell correction of 75% has been used at saddle point with respect to that at ground state in this calculations. The reduced value of pre-scission neutron multiplicity for $^{12}C+^{198}Pt$ system compared to that of $^{12}C+^{194}Pt$ can be accounted for the shell closure effects as the CN has 126 neutrons even though it has larger number of neutrons.

Fig.3 compares the total neutron multiplicities for both the systems as a function of the total available excitation energy of the fissioning system. The figure shows a smooth variation with available excitation energy with average number of neutrons emitted per MeV of available excitation energy ($M_{total}/Ex+Q_{fiss}$-TKE); its value is 0.078 ± 0.019 and 0.12 ± 0.023 for $^{12}C+^{198}Pt$ and $^{12}C+^{194}Pt$ systems respectively. The lower value for the former case clearly shows a suppression in total number of neutrons emitted emphasising the effect of neutron shell closure.

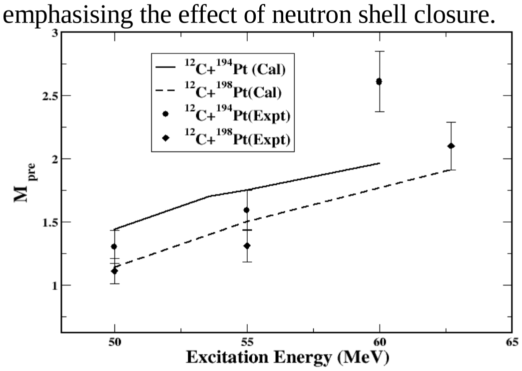

Fig.2 Experimental pre-scission neutron multiplicities along with the statistical model calculation results.

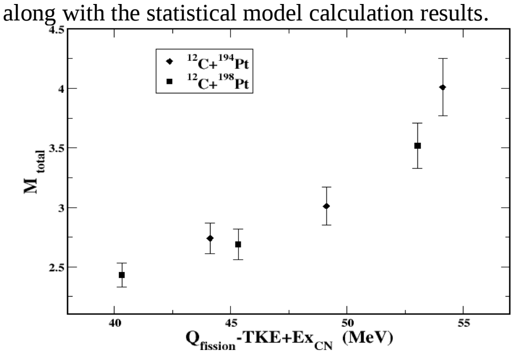

Fig.3 Experimental total neutron multiplicities

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