STUDY OF DISSIPATION STRENGTH AND ROLE OF SHELL CLOSURE IN FISSION DYNAMICS AT HIGH EXCITATION ENERGIES

A THESIS
Submitted to the
FACULTY OF SCIENCE
PANJAB UNIVERSITY, CHANDIGARH
for the degree of

DOCTOR OF PHILOSOPHY

2012

VARINDERJIT SINGH

CENTRE OF ADVANCED STUDY IN PHYSICS
DEPARTMENT OF PHYSICS, PANJAB UNIVERSITY
CHANDIGARH-160014
(INDIA)

Author: Varinderjit Singh Supervisor : Dr. Bivash Ranjan Behera

Date of Viva: 3rd Jan. 2013

Date of Award: 4th Feb. 2013

Summary

My thesis work was mainly focused on the study of the effect of shell closure on fusion-fission dynamics. Main idea behind this study is to see the variation of dissipation strength for shell closed and non-shell closed compound nucleus. For this study, ^{213,215,217}Fr compound nuclei were populated by bombarding ^{19}F beam on ^{194,196,198}Pt targets. Out of these, one compound nucleus is shell closed (N=126) and the other two are away from shell closure (N=128 and 130). A number of probes exist to study dissipation effects like neutron multiplicity, charged particle multiplicity, evaporation residue cross-sections, fission cross-sections, crystal blocking, K-shell ionization and fission fragments mass-energy correlation measurements. Out of these probes, we have used neutron multiplicity, fission cross-sections and evaporation residue cross-sections measurements for the present thesis work. A comprehensive knowledge of these processes will be helpful for better understanding of the shell effects on fission dynamics, which will help in understanding the production mechanism of super heavy elements.

In neutron multiplicity measurements, neutrons were detected in coincidence with fission fragments and contributions from pre-scission and post-scission components were extracted using three point moving source fitting. It is observed from the experimental results that pre-scission neutron multiplicities are less for shell-closed compound nucleus as compared to that of non-shell closed compound nuclei. The statistical model calculations were also carried out using Bohr-Wheeler and Kramers modified fission widths. The shell correction in level density was taken into account using Ignatyuk prescription. The statistical model was modified to use shell corrected fission barrier and experimental masses instead of liquid drop model masses. The statistical model calculations with Bohr-Wheeler fission width explains the neutron multiplicities at the lowest excitation energy, but under-predicts the same at higher energies. Detailed statistical model calculations with Kramers modified fission width were also carried out to extract the magnitude of dissipation strength. The reduced dissipation coefficient (β)

was treated as a free parameter for fitting the experimental results. It was observed that the strengths of the reduced dissipation coefficient required for non-shell closed nuclei are nearly same, though it is suppressed for closed-shell nucleus at low excitation energy. This indicates that the shell-assisted increase in the survival probability of shell closed compound nucleus can be offset to some extent owing to the reduction in dissipation coefficient. This may adversely affect the synthesis of super-heavy elements.

This study was extended to the measurements of fission and evaporation residues cross-sections for the same systems. The experimental fusion cross-sections were obtained by adding both fission and evaporation residues cross-sections. The experimental fusion cross-sections were fitted using coupled channel calculations (CCDEF) and compound nucleus spin distributions were obtained for each compound nuclei at various excitation energies. These spin distributions along with the experimental fusion cross-sections were fed as input to the statistical model calculations (using same code as used for neutron multiplicity analysis). It is observed that the statistical model calculations without dissipation (Bohr-Wheeler fission width) over predict the measured fission cross-sections whereas, under predict evaporation residue cross-sections. Further the dissipation effects were added to the statistical model calculations (Kramers modified fission width) and simultaneous fitting of fission and evaporation residue cross-sections was carried out. It was observed that the dissipation strength required for shell closed compound nucleus is suppressed as compared to non-shell closed nuclei. From all these observations, it can be concluded that shell closure in compound nucleus results in the suppression of dissipation strength.

The lowering of dissipation strength observed for the shell closed compound nucleus can act as an input for designing the experiments for the search of super heavy elements. It has been observed earlier that the shell closure in compound nucleus provides extra stability to the compound nucleus and can results in enhancement of evaporation residue cross-sections, which in turn can enhance the survival probability of super heavy elements. On the other hand, the shell closure results in the lowering of dissipation strength as observed in the present study. The lowering of dissipation strength can provide a less hindered path to fission, which results in lowering of evaporation residues cross-sections and hence suppresses the survival probability of super heavy elements. The net enhancement or suppression of survival probability of super heavy element will be decided by the collective effect of both the effects mentioned above. Hence, while planing for some new experiments for the synthesis of super heavy elements, the lowering of dissipation strength due to shell closure in compound nucleus should also be taken into consideration.

Future plans

We have planned to modify the existing statistical model code with the inclusion of free energy as driving force instead of potential energy. The total energy change is given by $dE_{tot} = TdS - Kdq$ where Kdq is the work done and dS is the change in entropy. Using the relation $E_{tot} = F + TS$ in this formula, one obtains $K = -(\partial F(q,T)/\partial q)_T$, i.e. the driving force is negative gradient of the free energy with respect to the fission coordinate q at fixed temperature T. Considering the nucleus as a non interacting Fermi gas, the following expression will be used for the free energy F.

$$F(q,T) = V(q) - a(q)T^2$$

where T is the temperature of the system, $V(q)$ is the potential energy and $a(q)$ is the coordinate dependent level density parameter. The driving force is thus given as;

$$K = -(\partial F(q,T)/\partial q)T = -dV(q)/dq + (da(q)/dq)T^2$$

i.e. it consists of the usual conservative force $-dV(q)/dq$ plus a term which comes from the thermodynamical properties of the fissioning nucleus, which enter via the level density parameter $a(q)$, whose deformation dependence is now essential. The properties of the heat bath enter in the description via the temperature T, which is calculated from the internal energy E^* and the level density parameter a by the Fermi gas relation $T = \sqrt{E^*/a}$. An attempt will be made to see the effect of change in driving force on neutron multiplicity, evaporation residue cross-section and fission cross-sections. Basically it will be a new set of calculations compared to what is presented in the present thesis work.

On the experimental side, we have plan to use different probes to verify our observation of lowering of dissipation strength due to shell closure. The neutron multiplicities, fission cross-sections and evaporation residues cross-sections probes have been employed for the present study. Similar studies can also be performed using the other probes like charge particle multiplicities, GDR γ-rays multiplicities, fission-fragments mass-energy correlations, crystal blocking technique etc. There is a proposal to make a charged particle array using CsI detectors for charged particle multiplicity measurements. We have planned to measure the charged particle multiplicities for the same systems to enhance our understanding of the effect of shell closure on dissipation strength.