Investigation of fission barriers for compound nucleus with neutron number ≥ 126

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Introduction

The study of fusion-fission dynamics is an active area of research in nuclear physics. The main focus of this study is the synthesis of theoretically predicted super heavy elements (SHE). The knowledge of the fission barrier height is one of the essential ingredients for synthesis of SHE. The magnitude of fission barrier is not known exactly for a number of compound nucleus (CN) and its variation with neutron number is also not well understood till now. The height of the fission barrier is normally given as $B_f = B_f^m - \Delta W_{gs}$, where B_f^m is the liquid drop fission barrier and ΔW_{gs} is the shell correction energy. In a recent study by Sagaidak *et al.* [1] the fission barrier are deduced from the evaporation residue cross-sections and are compared with the predictions of various theoretical models. It is observed that the fission barrier drops with decrease in neutron number and the decrease is larger than predicted by theory. They have carried out this study for CN with neutron number less than 126 (shell closure). It is therefore interesting to see how the fission barrier varies with neutron number for neutron rich CN.

With this motivation the evaporation residue (ER) cross-sections for ^{19}F + ^{194,196,198}Pt are measured at beam energies between 101 to 137.3 MeV. Of the above systems, ^{19}F + ^{194}Pt populates ^{213}Fr (N = 126), a shell closed compound nucleus (CN) whereas, other systems populate ^{215,217}Fr (N = 128, 130) which are non-shell closed CN.

Experimental Arrangement

The experiment was carried out at HYbrid Recoil mass Analyzer (HYRA) using Pelletron + LINAC at IUAC, New Delhi. A pulsed beam of ^{19}F with repetition rate of 4 µs and energy varying from 101 to 137.3 MeV, was bombarded on isotopic enriched targets of ^{194}Pt (thickness, 265 µg/cm^2 on 10 µg/cm^2 C backing with enrichment > 96.5 %) and ^{196,198}Pt (thickness, 170 µg/cm^2 on 20 µg/cm^2 C backing with enrichment > 91.6 %). The targets were placed at the center of 120 mm diameter scattering chamber and two Si surface barrier detectors were mounted at ± 23° (at distance of 23 mm from target position) with respect to the beam direction. These detectors were used to monitor the beam flux and normalize the ER yield to obtain absolute ER cross-section. For more details about experimental set-up, see Ref. [2].

Data analysis and results

The total ER cross-section can be obtained by using the expression

$$\sigma_{ER} = \frac{Y_{ER}}{Y_M} \frac{\Omega_M}{\eta_{HYRA}} \left(\frac{d\sigma}{d\Omega}\right)_{Ruth}$$

where Y_{ER} is the evaporation residue counts, Y_M is monitor counts, Ω_M is solid angle of monitor detector, η_{HYRA} is transmission efficiency of HYRA and $(d\sigma/d\Omega)_{Ruth}$ is differential Rutherford cross-section. The transmission efficiency of HYRA is obtained using the ER cross-section measured by Mahata *et al.* [3] at low beam energies. The total ER cross-sections obtained for all the three CN are shown in Fig. 1.

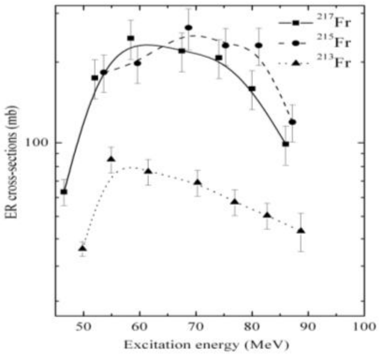

Fig. 1: The ER cross-sections for different CN under study. Lines are to guide the eyes.

Statistical model Calculations

The experimentally obtained ER cross-sections are compared with statistical model calculations. The statistical model code used in the present study considers emission of light particles (proton, neutron and alpha), γ-ray and fission as the possible decay modes of an excited CN. The decay widths for light particles are obtained from the Weisskopf formula and for fission the Bohr-Wheeler fission width is used. The level density parameter has been taken from the work of Ignatyuk [4] and is given as

$$a(E^*) = \overline{a}\left(1 + \frac{f(E^*)}{E^*}\delta W\right)$$

with

$$f(E^*) = 1 - \exp(-E^*/E_d)$$

where E^* is the CN excitation energy and E_d is damping factor (which decides how the shell effect wash out with excitation energy). The value of E_d is chosen to be 18.5 MeV. The ER cross-sections measured in the present work are combined with the fission cross-section obtained by Mahata *et al.* [3] and total fusion cross-sections are thus obtained at lower energies. The experimental fusion cross-sections are fitted with coupled channel calculations (CCDEF). The fusion cross-sections at higher energies are then obtained from CCDEF by using the same parameters which fit fusion cross-sections at lower excitation energies. The CN spin distributions obtained from the CCDEF calculations are used as input for statistical model calculations.

It is observed that the statistical model predicted ER cross-sections over predict the experimentally obtained ER cross-sections. Hence a fission barrier scaling factor (k_f) has been used to fit the experimental ER cross-sections. In the present work, the scaling factor is applied to the finite-range liquid drop model fission barrier and no shell correction is added to this fission barrier. It is interesting to see that the k_f required to fit the experimental ER cross-sections is not constant for all excitation energies but shows an excitation energy dependence as given in Fig. 2.

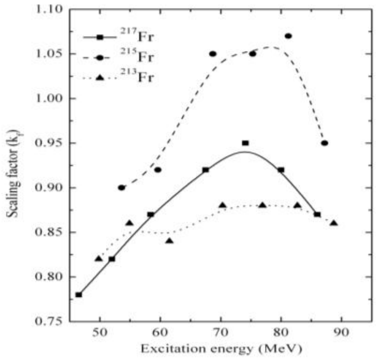

Fig. 2: The values of k_f required to fit the experimental ER cross-sections as a function of excitation energy.

It is clear from the Fig. 2 that the lowering of fission barrier is maximum for ^{213}Fr (shell closed CN) as compared to the other two CN. This finding is somewhat surprising in the light of the general expectation that shell closure gives rise to additional stability (and consequently larger fission barrier) for shell closed nuclei and hence requires further investigations. It is also observed that the magnitude of reduction in fission barrier decreases with increase in the excitation energy (i.e. value of k_f increases with excitation energy).

References

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