Statistical Model Calculations for the decay of ^{210}Rn Compound Nuclei at near barrier and above barrier energies

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Introduction

Heavy ion fusion-fission reactions studies is one of the major field of research in nuclear physics as it opens a gateway for the synthesis of super heavy elements (SHE). The dissipation effects in the fusion-fission reactions is investigated both experimentally and theoretically. Well known experimental probes are light particle multiplicities, Evaporation Residue(ER) cross-sections and fission fragments mass and angular distributions. Theoretically, statistical model is very helpful in explaining the decay of compound nucleus (CN). The de-excitation path of CN is hindered due to the collective motion of nucleons. This fission hindrance can be accounted by dissipative strength parameter β . Due to this dissipation, a large number of light particles emission takes place which are not explained quantitatively by SM. However, by the introduction of β parameter in SM, fusion-fission can be explained completely. In SM calculations the experimental fission/ER cross-sections are fitted by reducing the fission barrier and thus consequently increasing the fission probability. However, an opposite requirement arises in the analyses of multiplicities of light particles and photons emitted by a compound nucleus (CN) prior to fission. In this case, it was early recognized that a fission hindrance is necessary to explain the experimental data.

In various SM calculations, at least two of the input parameters, namely the fission barrier, the level density parameter, the fission delay time or the dissipation strength, are required to be adjusted for simultaneous fitting of the fission/ER and neutron multiplicity data[1].

In present work theoretical calculations are performed with an extended version of statistical model for the systematic study of ^{210}Rn CN populated through ^{16}O + ^{194}Pt system at various sub-barrier and above barrier energies.

Statistical Model

The Statistical model (SM) is very helpful in understanding the decay mechanism of CN. Now an extended version of SM has been recently introduced which includes the collective enhancement of level density (CELD) to calculate both particle decay widths and fission decay width. The effect of K-orientation of CN spin on fission width is also considered in this model. During calculations of decay widths, it considers shell corrections in both nuclear level density and fission barrier. The total level density used in this model is given by

$$\rho(E^*,l) = K_{Coll}(E^*,l) \,.\, \rho_{intr}(E^*,l)$$

where, K_{Coll} is collective enhancement factor taken from the works of Ignatyuk et al [2]. $\rho_{intr}(E,l)$ is the intrinsic level density and is calculated by the relation[3]

$$\rho_{intr}(E^*,l) = \frac{2l+1}{24}\left[\frac{\hbar^2}{2\Im}\right]^{3/2}\frac{\sqrt{a}}{E^{*2}}\exp(2\sqrt{aE^*})$$

where, $\Im$ is the rigid body moment of inertia and l is the angular momentum of the CN, ‘a’ is the level density parameter and is related to the nuclear temperature ‘T’ according to the Fermi gas model as E*= aT^2.

The Kramer’s modified fission width used is given by[4]

$$\Gamma_{Kramer} = \Gamma_{BW}\left(\sqrt{1+\left(\frac{\beta}{2\omega_s}\right)^2} - \frac{\beta}{2\omega_s}\right)$$

where, Γ_{BW} is the Bohr-Wheeler fission width, ω_s is the frequency of harmonic oscillator potential and β is the dissipation coefficient. Finite Range liquid Drop Model

(FRLDM) fission barrier is used in calculations without any scaling factor.

The spin distribution of the compound nuclei formed is an important parameter in the calculations of SM. This spin distributions is obtained from coupled-channel calculations considering the low-lying collective states of the target nuclei. The dissipation strength is the only adjustable parameter in the aforementioned model.

Results and Discussion

Statistical Model calculations have been performed for fitting fission cross section[5], ER cross section[6] and pre-scission neutron multiplicity[7] for ^{210}Rn populated through ^{16}O + ^{194}Pt at different excitation energies. All the three calculations(fission cross section, ER cross section, neutron multiplicity) have been performed using the same input parameters. These calculations are performed with different dissipation strengths. It is found that, at lower excitation energies, $\beta = 0$ sufficiently reproduce fission and ER cross-sections as shown in Fig 1 and Fig 2(b) respectively. However, dissipation strength of $\beta = 1$ to 1.5 is required to fit experimental data at intermediate energies of 77-85MeV.

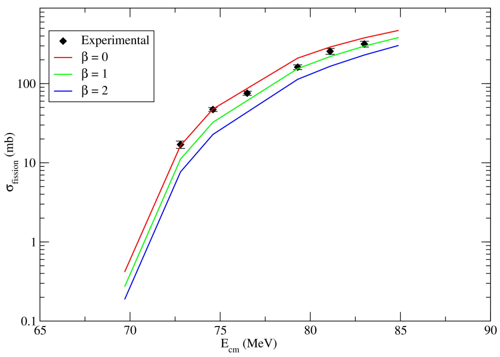

Fig1. Experimental data of fission cross section along with SM calculations versus energy in center-of-mass(E_{cm}) in MeV

At much higher energies, $\beta = 2$ fits ER cross sections. At higher energies particle emission become significantly large due to more dissipation in fusion-fission process. So, we require high dissipation strengths to fit experimental data at high energies.

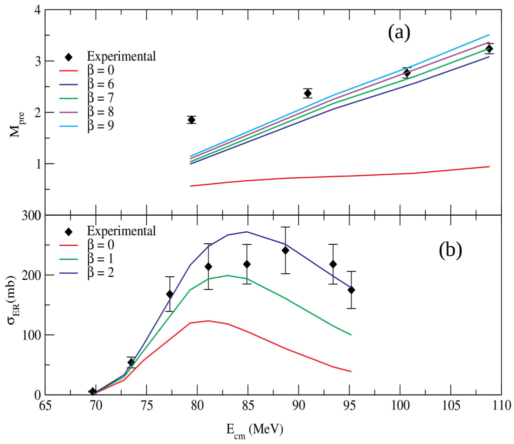

Fig2. Experimental data of ER cross section (b) and Neutron multiplicity (a) along with SM calculations versus energy in center-of-mass(E_{cm}) in MeV.

We also found that, neutron multiplicity increases with increase of β values but still remains underestimated for β upto 9 x 10^{21} sec^{-1} at lower energies(Fig2a) but fits at higher energies. We conclude that, the same β values fit both fission and ER cross-section in the given range of energies.

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