Cross-section of $^{181}Re^*$ using modified scission point model

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Introduction

The phenomenon of nuclear fission has been intensively investigated since its discovery. Similar to low energy and spontaneous fission of actinides, induced fission of medium mass nuclei is also gaining equal importance in the field of fission studies. A new statistical scission-point model, called SPY [1] has been modified to study the yield distributions for thermal neutron induced fission of actinides where the role of angular momentum is not involved [2]. However, in the case of heavy ion or light particle induced reaction of finite energy, the role of angular momentum is important. In the present work, angular momentum included modified scission point model has been applied to evaluate fission fragment properties for $^{181}Re^*$ at three different lab energies which has been investigated recently by Arshiya Sood *et al.,* [3].

Model

The system at scission is modelled by two coaxial nuclei with nuclear surfaces separated by a fixed scission distance d. The fragment shapes are described by quadrupole deformations β. The available energy (E_A) of the system at scission configuration is defined as,

$$\begin{aligned} E_A =& E_1(Z_1, N_1, \beta_1) + E_2(Z_2, N_2, \beta_2) + \\ & E_{Coul}(Z_1, N_1, \beta_1, Z_2, N_2, \beta_2, d) + \\ & E_{nucl}(Z_1, N_1, \beta_1, Z_2, N_2, \beta_2, d) + \\ & E_{rot}(Z_1, N_1, \beta_1, Z_2, N_2, \beta_2, l, d) - E_{CN} \end{aligned}$$

where A_i, Z_i, β_i are the mass number, charge number, quadrupole deformation parameter of the individual fragments at the scission point and l is the angular momentum value. The suffix $i = 1, 2$ represents both heavy and light fragments respectively. The individual energies of the fragments E_i are evaluated as the sum of macroscopic liquid drop part and microscopic shell correction determined through Strutinsky prescription using Nilsson levels. Deformation dependent Coulomb E_{Coul}, nuclear E_{nucl} [4] and rotational E_{rot} [5] energies are used.

A given configuration is energetically reachable only if $E_A < 0$. By convenience, the absolute value of the available energy is used and only energetically reachable scission configurations are taken into account. Using maximum available energy criteria, the most favourable fragment deformation and fission channel is determined.

Yield

The probability of nuclear fission p yielding fragments (A_1, Z_1) and (A_2, Z_2) is :

$$p = \rho_1(l, E_1^*)\rho_2(l, E_2^*)$$

where the nuclear level densities [6] are given by :

$$\rho_i(l, E_i^*) = \frac{\exp S(l, E_i^*)}{T S_{max}}$$

with entropy S and normalization factor S_{max}. T is the temperature corresponding to the compound nucleus excitation energy. The excitation energy of deformed fragments at temperature T are evaluated by using Nilsson single particle levels through particle number and angular momentum conservation equations. The total probability for a particular fragmentation over all the partial waves is

$$P(A_i, Z_i) = \sum_{l=0}^{l_{max}} (2l + 1)p$$

where l_{max} is the limiting value of angular momentum. The relative yield at the point of

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scission is calculated as :

$$Y(A_i) = \frac{P(A_i, Z_i)}{\sum P(A_i, Z_i)}$$

Cross section

The cross section for the formation of fission fragments over all partial waves can be

$$\sigma = \frac{\pi}{k^2} \sum_{l=0}^{l_{max}} (2l+1) Y_l P_l; \quad k = \sqrt{\frac{2\mu E_{cm}}{\hbar^2}}$$

where μ is the reduced mass, E_{cm} is the centre of mass energy of the fissioning system, Y_l and P_l are the normalized statistical probability and penetration probability for each angular momentum in which the latter is evaluated using WKB approximation as

$$P_l = \exp\left[-\frac{2}{\hbar} \int_{R_a}^{R_b} \{2\mu\,[V(R) - Q_{eff}]\}^{1/2}\, dR\right]$$

The potential $V(R)$ is the sum of Coulomb, nuclear and centrifugal potential calculated for deformed fragments. For the decay of compound nucleus, the first turning point R_a is considered to be $R_a = R_1 + R_2 + \triangle R$ with $\triangle R$ as neck-length parameter. The potential $V(R_a)$ act as effective Q value, Q_{eff}, and R_b is the second turning point satisfying $V(R_a) = V(R_b) = Q_{eff}$.

Results

Within the decribed model, the cross-section values for the binary decay of $^{181}Re^*$ compound nucleus formed through the entrance channel $^{12}C+^{169}Tm$ reaction are computed and compared with the experimental results of Ref. [3] corresponding to three different incident energies of $E_{lab} \approx$ 77.18, 83.22 and 89.25 MeV with the limiting angular momentum values of $\approx 37\ \hbar$, $\approx 41\ \hbar$, and $\approx 45\ \hbar$, respectively. A broader and symmetric mass distribution, is obtained comparing fairly with the experiemental observations. The calculations are restricted only to the mass window as reported in Ref. [3]. The cross section values are found to be highly sensitive to the choice of scission distance d and neck-length parameter $\triangle R$. For the present study, it is taken as $\triangle R$ = 1 fm and d = 0.8 fm for all channels and for all lab energies. The values for these two parameters were not fine tuned to fit with experimental data but has been chosen in such a way that calculated cross section has better agreement with experimental data.

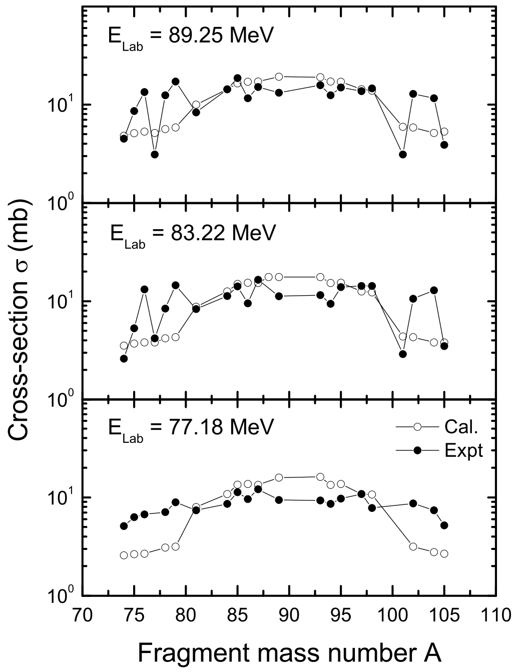

FIG. 1: Fission fragment cross-sections compared with experimental data for three different lab energies.

References

[1] J.-F. Lemaitre *et al.,* Phys. Rev. C **92**, 034617 (2015).
[2] C. Karthika and M. Balasubramaniam, E. Phys. J. A (2018) - to be submitted.
[3] Arshiya Sood *et al.,* Phys. Rev. C **96**, 014620 (2017).
[4] V.Yu. Denisov *et al.,* Phys. Rev. C **95**, 014605 (2017).
[5] A. V. Andreev *et al.,* Phys. Rev. C **86**, 044315 (2002).
[6] N. Arunachalam *et al.,* Phys. Rev. C **55**, 4 (1997).