Fragment Mass Distribution of Radioactive $^{238}U^*$ Nucleus

Gurvinder Kaur, Amandeep Kaur and Manoj K. Sharma*
School of Physics and Materials Science, Thapar University Patiala, Punjab
E-mail: msharma@thapar.edu

Abstract

The decay of compound nucleus $^{238}U^*$, formed in the neutron induced reaction is studied using the dynamical cluster decay model (DCM) at two excitation energies lying across the Coulomb barrier. The role of deformations in the decay of $^{238}U^*$ has been studied by considering the quadrupole deformations (β_2) within the optimum orientation approach (θ_i^{opt}) and with the spherical choice of fragmentation. The calculated results show an excellent agreement with the experimental data for the fission cross sections ($\sigma_{fission}$).

1. Introduction

In recent times the study of radioactive nuclei has gained much more importance owing to their tremendous advantage in the field of science. To utilize the qualitative features of the radioactive nuclei requires a thorough understanding of the formation and dynamic aspects of these nuclei. In order to achieve this several major and minor actinides have been studied in various forms, neutron induced reactions being one of them.

The excitation functions of compound nucleus $^{238}U^*$ formed in n-induced reaction have been investigated by Burke *et. al.*, [1] at a number of energies spread across the Coulomb barrier. In reference to this experiment [1], we intend to study the decay of $^{238}U^*$compound nucleus using the dynamical cluster decay model (DCM) [2-4]. In the present work, to have better understanding of the dynamics of $^{238}U^*$ system, the calculations have been done at extreme excitation energies lying across the Coulomb barrier i.e. at $E_{c.m.}$=0.67 MeV and at $E_{c.m.}$=18.60 MeV. The structural features in the decay of compound nucleus under study are examined in the form of potential energy surfaces. An interesting feature of DCM is that the deformation and orientation effects are duly incorporated in it. Thus in order to analyze the role of deformations, the fission cross sections have been calculated using the dynamical cluster-decay model (DCM) for the spherical choice of fragmentation and with the inclusion of β_2 deformations within "optimum" orientation (θ_i^{opt}) approach. The deformations $\beta_{\lambda i}$, in DCM are taken from the theoretical estimates of Moller and Nix [5] while the optimum orientations of the hot fusion process are employed in reference to [4].

The organization of paper is as follows: A brief account of the dynamical cluster-decay model (DCM) is presented in section 2. The calculations and results for fission excitation functions are discussed in section 3. Finally, the results are summarized in section 4.

2. The Dynamical Cluster-Decay Model (DCM)

The work presented here deals with the study of dynamics involved in the neutron induced reaction using Dynamical Cluster-decay Model (DCM) [2-4], where the decay of hot (T≠0) and rotating (ℓ≠0) compound nucleus with effects of deformations and orientations of two nuclei or fragments included is studied by applying dynamical collective clusterization process. The temperature T is related to CN excitation energy as

$$E_{CN}^*=(A_{CN}/9)T^2-T \qquad (1)$$

The DCM explains the nuclear dynamics by mass asymmetry coordinates defined as $\eta_A=(A_1-A_2)/(A_1+A_2)$, the relative separation R, the multipole deformations $\beta_{\lambda i}$ (λ=2, 3, 4), and orientations θ_i (i=1,2) of two nuclei or fragments (1 and 2 represent respectively, the heavy and light fragments). With all these coordinates the compound nucleus decay cross-section for ℓ-partial waves is given by

$$\sigma=\frac{\pi}{k^2}\sum_{l=0}^{l=l\,max}(2l+1)P_0P\,;\,k=\sqrt{\frac{2\mu Ecm}{\hbar^2}} \qquad (2)$$

where the maximum angular momentum ℓ_{max} is fixed for the vanishing light particle cross-section $\sigma_{LP}\rightarrow 0$. The preformation probability P_0 refers to η motion and the penetrability P to R motion. The penetration probability P in equation (2) is calculated using the WKB integral as.

$$P=\exp\left(-\frac{2}{\hbar}\int_{R_a}^{R_b}\{2\mu[V(R)-Qeff\,]\}^{\frac{1}{2}}dR\right) \qquad (3)$$

R_a, i.e. the first turning point of the penetration path(s) is defined as $R_a = R_1(\alpha_1,T) + R_2(\alpha_1,T) + \Delta R(T) = R_t(\alpha, T) + \Delta R(T)$. The $\Delta R(T)$ is the neck-length parameter that assimilates the neck formation effects between two nuclei. The preformation probability P_0 is calculated by solving stationary Schrodinger equation in η, at a fixed $R = R_a$, The expression for P_0 is given as

$$P_0 = |\varphi_R(\eta(A_i))|^2 \sqrt{\beta_{\eta\eta}} \frac{2}{A_{CN}} \qquad (4)$$

where $\beta_{\eta\eta}$ are the smooth hydrodynamical masses [6].

3. Results and Discussions

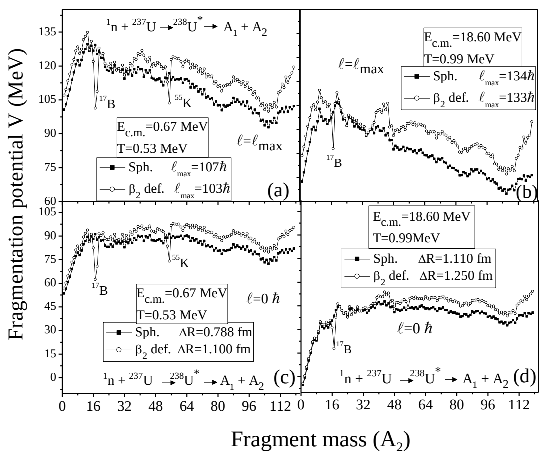

Figure1. Fragmentation potential for spherical and β_2 deformed approach at extreme energies across the barrier at (a,b) ℓ= ℓ$_{max}$ and (c,d) ℓ= 0 ħ .

The structural effects in the dynamics of $n+^{237}U \rightarrow ^{238}U^*$ reaction are addressed on the basis of the fragmentation potential V (MeV) and the preformation probability of the decaying fragments. Fig.1 shows the variation of fragmentation potential as a function of fragment mass (A_2) at both the energies across the barrier for ℓ= ℓ$_{max}$ [parts (a,b)] and ℓ =0 ħ [parts (c,d)]. Comparing the potential energy surfaces for spherical and deformed choice of fragments it is observed that fragmentation potential remains identical for evaporation residue ($A_2 \leq 4$) and fission fragments. A slight change in structure in the intermediate mass region is observed on going from below barrier to above barrier energy. The only parameter of the model, ΔR used to obtain the fission cross sections of 0.42b and 1.2b is different for spherical and β_2 choice of fragmentation being 0.788fm and 1.110fm for spherical case at below barrier energy i.e. $E_{c.m.}$=0.67MeV and at above barrier energy, $E_{c.m.}$=18.60MeV respectively. However, with the inclusion of deformations higher ΔR values are

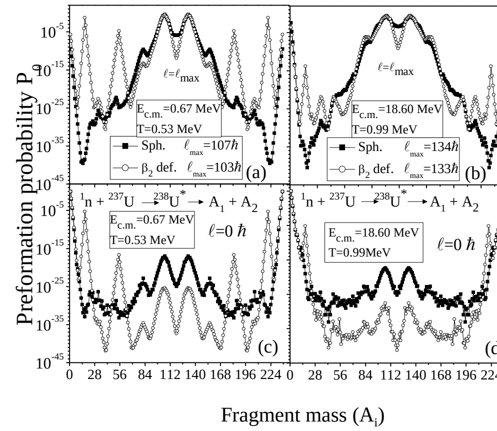

Figure2. Same as fig.1 but for preformation probability

involved being 1.1fm and 1.250fm at extreme energies. Fig.2 shows the variation of P_0 as function of fragment mass A_i. Comparing Fig. 2(a,b) and 2(c,d) it is observed that at lower angular momentum values the contribution of evaporation residues is more whereas at higher angular momentum the fission fragments are dominating. Although the structure is almost similar for spherical and deformed choices, the role of deformation is more evident at lower energy. The fragment mass distribution is more symmetric for spherical fragmentation and is relatively lesser for the β_2 choice of fragmentation.

4. Conclusion

The DCM based fission cross sections for the decay of $^{238}U^*$ are in nice agreement with experimental data. The effect of deformations is more significant at below barrier region as compared to that for above barrier. Moreover, the structure of potential energy surfaces is almost identical for evaporation residues and fission fragments for both the spherical and deformed choice of fragmentation. The mass distribution is more symmetric for the spherical case and relatively less for β_2 deformed choice.

5. References

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