Fission decay analysis of ^{242}Pu* using the clusterization process

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Introduction

The study of nuclear fission is of great significance for not only to understand the nuclear structure and dynamics involved but also to explore the field of reactor physics. Apart from being a key factor in determination of nuclear power, the neutrons have proved to be an adequate tool in understanding the reaction dynamics by providing useful information about nuclear structure and related aspects. The precise knowledge of n-induced fission cross-sections is significantly important for optimizing various properties of reactor systems which in turn motivate us to explore the dynamics of reactions involving neutron as projectile and actinide nuclei as target.

In this paper, the decay of excited trans-actinide ^{242}Pu* nucleus is studied, by using the dynamical cluster-decay model (DCM) [1], in reference to the recent experimental data [2] where ^{241}Pu(n,f), the n-induced fission of ^{241}Pu, cross sections are determined as a function of excitation energy E^* of ^{242}Pu* over the energy range E^*=17.0-22.0 MeV, equivalently the incident n-energy range of E_{lab}=11.0-16.0 MeV, by using the surrogate ratio method (SRM) in ^{238}U(^{6}Li,d)^{242}Pu and ^{232}Th(^{6}Li,d)^{236}U transfer reactions at E_{lab}=39.6 and 39.0 MeV, respectively. Importantly, a number of factors and properties influence the fusion-fission process, which need to be handled with proper care in order to make some meaningful predictions. One such aspect, which plays a significant role in the fusion-fission dynamics, is the deformed shapes of target and projectile nuclei, and the decay fragments. Since the collective clusterization approach is being used in the calculation of fragmentation profile of decaying nucleus, the shapes of all possible fragments are considered to be important. The motivation of the present study is to address the fission cross-sections of ^{242}Pu* by taking into account the role of deformations, within the collective clusterization approach of the DCM.

Methodology

The DCM is a two step model involving preformation probability P_0 of the decay products formed in the mother nucleus and penetration P of the fragments/ clusters through the interaction barrier. P_0 is obtained by solution of stationary Schrödinger equation, whereas the penetrability P is calculated via WKB approximation. Note that the structure information of the compound nucleus enters via the preformation factor through the fragmentation potential $V_R(\eta, T)$, defined as:

$$\begin{aligned} V_R(\eta,T) &= \sum_{i=1}^{2}[V_{LDM}(A_i,Z_i,T)] \\ &\quad + \sum_{i=1}^{2}[\delta U_i]\exp(-T^2/T_0^2) \\ &\quad + V_C + V_P + V_\ell \end{aligned} \qquad (1)$$

where V_C, V_P and V_ℓ are, respectively, the T-dependent Coulomb, nuclear proximity and centrifugal potentials for deformed and oriented nuclei. V_{LDM} is T-dependent liquid drop energy and δU is the empirical shell correction which allows us to define the binding energy B of a nucleus at temperature T.

Using both P_0 and P, the CN decay cross-sections can be calculated using partial wave

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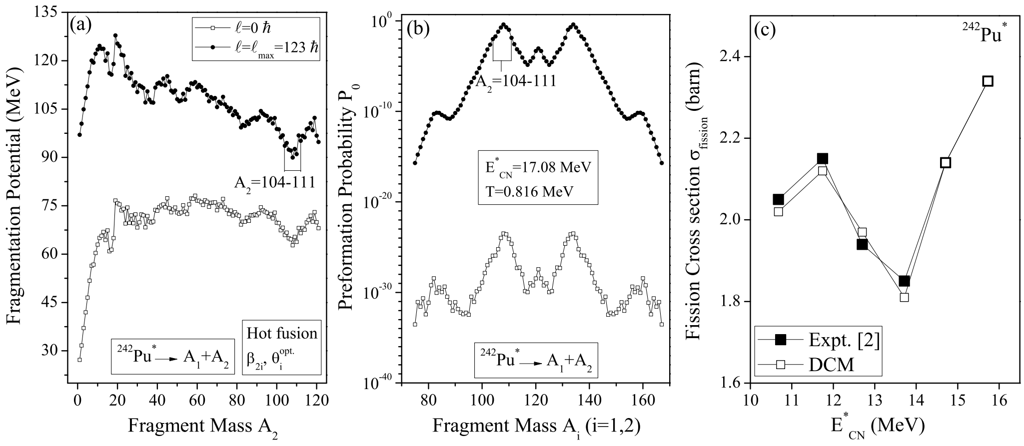

FIG. 1: (a) The fragmentation potentials for the decay of ^{242}Pu* plotted at extreme values of angular momentum for β_2 deformed choice, at neck-length value of ∼1.23 fm. (b) Same as (a) but for preformation probability P_0. (c) Comparison of the DCM based fission cross-sections with measured data [2] over a wide range of excitation energies.

analysis:

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0 P; \qquad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{2}$$

Here, ℓ_{max} is the maximum angular momentum, fixed for the light particles cross section, (σ_{ER}) tending to become negligibly small, i.e., $\sigma_{ER} \to 0$ at ℓ=ℓ_{max}.

Calculations and Results

In order to look for the dynamics of ^{241}Pu(n,f) reaction, we have applied the DCM over a wide range of excitation energies ranging from E^*_{CN}=17.0-22.0 MeV, equivalently the incident neutron energy range of E_{lab}=11.0-16.0 MeV, to look for the possible role of deformations and orientations in the decaying nucleus. The calculations have been performed using quadrupole (β_2) deformed fragments having "optimum orientations $\theta_i^{opt.}$ of hot (compact) configurations [3]. Note that ΔR, the neck-length is the only parameter of the model that assimilates the deformation and neck formation effects between two nuclei.

Fig. 1(a) illustrates the variation of fragmentation potential V (MeV) for decay of ^{242}Pu* at E^*_{CN}=17.08 MeV for ℓ=0 and ℓ=ℓ_{max} cases. Although the characteristic behavior of potential energy surfaces is different at the extreme ℓ values, the light particles are found to be more (energetically) prominent at lower ℓ-values whereas fission fragments start dominating (deeper minimum) with increase in ℓ-value. This is further emphasized in Fig. 1(b) where variation of preformation probability P_0 is plotted as a function of fragment mass A_2. One can clearly see that the fragments in the mass range A_2=104-111 (plus their complementary heavy fragments), corresponding to asymmetric fission peaks, are found to contribute towards the fission cross-section. Interestingly, the DCM calculated fission cross-sections find nice agreement with experimental data (refer, Fig. 1(c)) at a constant neck length value of ΔR∼1.23 fm. In addition, the contribution of light-particles cross section σ_{LPs} is also estimated, which comes out to be negligibly small (∼10^{-5} barn) at all energies thereby suggesting the dominance of fission decay mode in the present reaction, and hence provides an ideal case to look for the explicit role of decay fragments in the dynamics involved.

References

[1] G. Sawhney *et al.*, Phys. Rev. C **92**, 064303 (2015).

[2] V. V. Desai *et al.*, Phys. Rev. C **87**, 034604 (2013).

[3] R. K. Gupta *et al.*, J. Phys. G: Nucl. Part. Phys. **31**, 631 (2005).