Decay of ^{241}Pu* formed in ^{9}Be + ^{232}Th reaction around the Coulomb barrier.

Gudveen Sawhney and Manoj K. Sharma*
School of Physics and Materials Science,
Thapar University, Patiala - 147004, INDIA

Introduction

Fusion reactions induced by weakly bound projectiles have contributed immensely in the development and understanding of nuclear reaction dynamics in recent years. The entrance channel properties of the reacting systems play a major role in the nuclear reaction dynamics of non compound nucleus (NCN) processes such as quasi fission (QF), incomplete fusion (ICF), etc. Several measurements involving reactions with lighter projectiles like ^{6,7}Li, ^{9}Be, ^{10,11}B and ^{12}C on deformed actinide targets, have found that the measured anisotropies exceed the standard statistical saddle-point model (SSPM) predictions by large amounts, at sub-barrier energies and this anomalous behavior of the fragment anisotropies has been a subject of extensive investigations both experimentally and theoretically in recent past. It has been reported in [1] that anomalous fragment anisotropies in case of highly fissile target nuclei arise due to admixture of compound-nucleus (CN) fission along with noncompound nucleus (NCN) fission events in form of QF, ICF or DIC etc. Thus it becomes quite interesting to study the decay path of nuclear systems in actinide region in order to see impact of these nuclear phenomena.

In reference to recent experiment [2], we have investigated the fission fragment cross sections and anisotropies for the ^{9}Be + ^{232}Th reaction over a wide range of energies spread around Coulomb barrier, using Dynamical Cluster-decay Model (DCM) [3].

*Electronic address: msharma@thapar.edu

The Model

In DCM, we use the collective co-ordinates of mass and charge asymmetries, 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, which allow to define the decay cross-section, in terms of the partial waves with μ as the reduced mass, as

$$\sigma = \frac{\pi}{k^2}\sum_{l=0}^{l_{max}}(2l+1)P_0P; \qquad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}}, \tag{1}$$

P_0, the pre-formation probability, is the solution of stationary Schrödinger equation in mass asymmetry coordinate η and P is the WKB penetrability of preformed fragments or clusters in R-motion. ℓ_{max} is the maximum angular momentum, which is fixed at point where the light particle cross-section become negligible $\sigma_{LP} \rightarrow 0$ or penetrability becomes unity. The only parameter of the model is the temperature dependent neck length parameter ΔR(T). The fission fragment anisotropy A is also calculated in DCM within SSPM approach which relates the total ℓ value (equivalently ℓ_{max}) of the CN, the effective moment-of-inertia I_{eff} of the fissioning nucleus and the temperature T at the saddle point, as

$$A = 1 + \langle \ell^2 \rangle / 4K_0^2, \tag{2}$$

with

$$K_0^2 = T \times I_{eff}/\hbar^2, \tag{3}$$

where I_{eff} is calculated by using the finite-range rotating liquid drop model [4].

Calculations and discussion

The decay of compound nucleus ^{241}Pu* formed in ^{9}Be + ^{232}Th reaction [2] over a

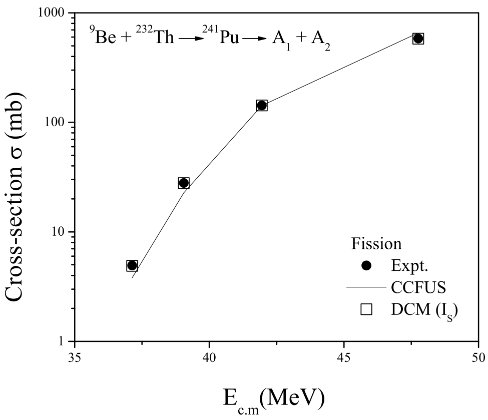

FIG. 1: Experimental fission cross-section σ_{fiss} along with coupled-channel code CCFUS predictions compared with calculations using DCM.

wide range of c.m. energies (37 - 48 MeV), is studied by using the Dynamical Cluster-decay Model (DCM). The calculations are made for quadrupole (β_2) deformed fragments having "optimum" orientations for hot (compact) configurations. The fragments in mass range A_2 = 100 - 113 seem to contribute towards fission fragments and the fragmentation behavior remains asymmetric for beam energies both below and above the Coulomb barrier. The symmetric fission fragments contribute about 0.6 % to the FF (fusion fission) cross-section which simply mean that an asymmetric fragmentation path is preferred in the decay of ^{241}Pu* nuclear system. Interestingly our DCM calculated fission cross-sections, using sticking moment of inertia (I_S) are in excellent agreement with experimental data along with the theoretical predictions of coupled channel code for fusion (CCFUS) at all the four reported energies as shown in Fig.1. Also, the evaporation residues (ER) as expected are negligibly small and don't contribute towards fusion excitation functions of this reaction. The DCM calculated σ_{fiss} fit the data very nicely within one parameter fit of ΔR which is found to depend strongly on limiting ℓ_{max} value and hence in turn depends on the use of sticking or non-sticking limit of moment-of-inertia for angular momentum effects in potential.

We have also calculated fission-fragment anisotropies (not shown here) using equation (2) with DCM based parameters, by taking ΔR values same as that for fitting the fission data. The DCM based fission-fragment anisotropies are found to be consistent with the SSPM, preequilibrium fission (PEQ) predictions and experimental data, for the above barrier energies. For energies below the barrier, DCM calculated anisotropy values are smaller than experimentally observed anisotropies as that for PEQ and SSPM. The explanation for this behavior is attributed to possible break up of loosely bound projectile nucleus ^{9}Be as suggested in [2]. It will be of further interest to study ICF based cross-sections for ^{9}Be + ^{232}Th reaction using DCM. Important point to be noted here is that non sticking limit (I_{NS}) is preferred for the calculation of DCM based anisotropies, whereas sticking approach (I_S) is preferred for fitting fission cross-section data.

In summary fission cross-section of ^{9}Be + ^{232}Th reaction find nice comparison with experimental data and CCFUL results. The contribution of ER as expected is negligibly small for the fissile ^{241}Pu nucleus and asymmetric fragmentation is favored within DCM approach. DCM based anisotropies are consistent with SSPM, PEQ and experimental data at above barrier energies. Non sticking moment of inertia (I_{NS}) favors anisotropy calculations whereas sticking approach (I_S) is more suitable for fitting the fission cross-section data.

References

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