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# Study of the decay of $^{291}$115* formed in $^{48}$Ca+$^{243}$Am reaction

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**Abstract.** The decay of $^{291}$115* formed in $^{243}$Am+$^{48}$Ca reaction is studied using the dynamical cluster-decay model (DCM), including the possible effect of deformations. A comparative study of spherical and $\beta_2$-static deformed choices of fragmentation is made for the 2*n* evaporation residue (ER) of the compound nucleus (CN) $^{291}$115*. The heavier neutron clusters 3*n* and 4*n* could be fitted only after the inclusion of deformation effect in DCM. Symmetric fission is observed for the spherical approach, which changes to asymmetric one with inclusion of deformation effect. Also, a comparative analysis between spherical and deformed ($\beta_2$) cases of observed α-decay chains shows that the magnitude of penetration probability gets enhanced whereas preformation factor decreases due to decreased ΔR, when the α-daughter product is taken as spherical rather than deformed.

## 1 Introduction

Heavy ion reactions involving radioactive deformed actinide targets have been used extensively as a tool to synthesize neutron-rich nuclei in the superheavy mass region. The even-Z superheavy nuclei up to Z=118 are synthesized using various combinations of actinide targets with $^{48}$Ca beam, and the interest in dynamics of reactions for odd-Z nuclei in this mass region remains, since it gives a detailed information about the nuclear structure under extreme conditions. Broadly speaking, due to unpaired nucleons in these nuclei, strong hindrance of symmetric fission occurs and the probability of α-decay w.r.t. spontaneous fission increases immensely. To explore the structural and stability aspects of odd-Z region further, $^{243}$Am+$^{48}$Ca→$^{291}$115* [1] is studied within the framework of DCM [2-4]. For proton and neutron magic shells, we take Z=126 and N=184, as suggested by Gupta *et al.* [3]. The deformation effects are included upto $\beta_2$ with 'optimum' orientations. Also, we have studied the α-decay channel using the preformed cluster model (PCM) of Gupta and Malik [5], with the spherical as well as static $\beta_2$-deformed choices of fragmentation.

## 2 The Methodology

The dynamical cluster-decay model (DCM), for the decay of hot and rotating nuclei, is the reformulation of preformed cluster model (PCM), based on the quantum mechanical fragmentation

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theory (QMFT) [6,7], which, in binary fragmentation, uses the collective mass transfer process. In contrast to DCM, the PCM is applicable only to spontaneous fission and ground-state cluster decays where the angular momentum and temperature effects are absent.

In QMFT, the preformation probability $P_0$, which imparts structure information of the decaying nucleus, is calculated as the solution of stationary Schrödinger equation in mass asymmetry coordinate $\eta = (A_1-A_2)/(A_1+A_2)$, given as:

$$P_0 = |\psi[\eta(A_i)]|^2 (2/A_{CN})\sqrt{B_{\eta\eta}} \quad (1)$$

In the above Eq. (1), the mass parameters $B_{\eta\eta}$, representing kinetic energy term of Hamiltonian, are the smooth hydrodynamical masses [8], and the structure information of compound nucleus enters $P_0$ through the fragmentation potential $V_R(\eta, T)$, defined as

$$V_R(\eta,T) = \sum_{i=1}^{2}[V_{LDM}(A_i,Z_i,T)] + \sum_{i=1}^{2}[\delta U_i]\exp(-T^2/T_0^2) + V_c(R,Z_i,\beta_{\lambda i},\theta_i,T) + V_P(R,A_i,\beta_{\lambda i},\theta_i,T)$$
$$+ V_\ell(R,A_i,\beta_{\lambda i},\theta_i,T) \quad (2)$$

Here, $V_{LDM}$ is the T-dependent liquid drop model energy of Davidson *et al.* [9] and $\delta U$ is the 'empirical' shell correction from Myers and Swiatecki [10]. $V_C$, $V_P$ , and $V_\ell$ are, respectively, the T-dependent Coulomb, nuclear proximity, and angular momentum $\ell$-dependent potentials for deformed and oriented nuclei.

The barrier penetration probability P, referring to relative separation coordinate R, is the WKB integral

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

with $V(R_a, T) = V(R_b, T) = TKE(T) = Q_{eff}$ , where $R_a$ and $R_b$ are the first and second turning points of the penetration path, and $Q_{eff}$ is the effective Q-value of decay process.

## 2.1 The dynamical cluster-decay model (DCM)

In DCM [2-4], the compound nucleus decay cross-section, in terms of $\ell$ partial waves, is defined as

$$\sigma = \sum_{\ell=0}^{\ell_{max}}\sigma_\ell = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \qquad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (4)$$

where, for each $\ell$, the preformation factor $P_0$ refers to $\eta$-motion and the penetrability P` to R-motion via the interaction barrier V(R), given by Eqs. (1) and (3), respectively. $\ell_{max}$ is the maximum angular momentum, fixed for the light particles (here, only neutrons) cross section $\sigma_{ER}$ ($=\Sigma_x \sigma_{xn}$, $x$ = 2, 3, 4) tending to become negligibly small.

## 2.2 The preformed cluster model (PCM)

In PCM [5], the decay constant, and hence the decay half-life time, is defined as

$$\lambda = \upsilon_0 P P_0, \qquad T_{1/2} = \ln 2/\lambda , \quad (5)$$

with barrier impinging frequency $\upsilon_0 = \pi/k^2$.

The preformation probability $P_0$ is calculated in the same way as that for DCM, given by Eq. (1), where as the penetration probability P for PCM is defined in a slightly different way from the one for DCM. Here P is divided into three steps [5]. The three steps are: (a) the penetrability $P_i$ from $R_a$ to $R_i$,

(b) the (inner) de-excitation probability $W_i$ at $R_i$, taken as unity, i.e., $W_i=1$ for heavy cluster-decays , and (c) the penetrability $P_b$ from $R_i$ to $R_b$, giving

$$P = P_i W_i P_b \tag{6}$$

where $P_i$ and $P_b$ are the relevant WKB integrals.

# 3 Calculations and Results

The decay of compound nucleus $^{291}115^*$ has been studied in detail over a wide range of excitation energy $E_{CN}$=31 - 47 MeV, using DCM where static deformation effects are included upto $\beta_2$, within the hot 'optimum' orientation approach. The comparative analysis of spherical vs. $\beta_2$-static deformations is investigated explicitly for the 2*n*-evaporation residue, as only the 2*n* decay responds to spherical choice of fragmentation. However, the 3*n* and 4*n* decay cross-sections could be fitted only after the inclusion of deformation effects.

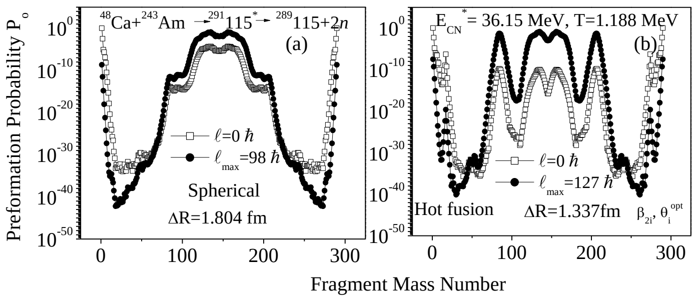


**Figure 1.** Preformation probability $P_0$ for the decay of $^{291}115^*$, for (a) spherical, and (b) $\beta_2$-deformed choice of fragmentation.

Fig. 1 shows more structure with the inclusion of deformation effect, which on the other hand exhibit smooth preformation profile for spherical choice. The potential energy surface, equivalently, the preformation factor $P_0$ in Fig. 1(a) for spherical case exhibits symmetric fission, whereas the same for deformed choice in Fig. 1(b) shows asymmetric peaks in heavy mass fragment region $A_2$=80-90 and 200-210. Another important observation is: the effects of angular momentum seem to remain absent for both (spherical and deformed) preformation paths of $^{291}115^*$, as no structural change is observed in going from $\ell$=0 to $\ell_{max}$.

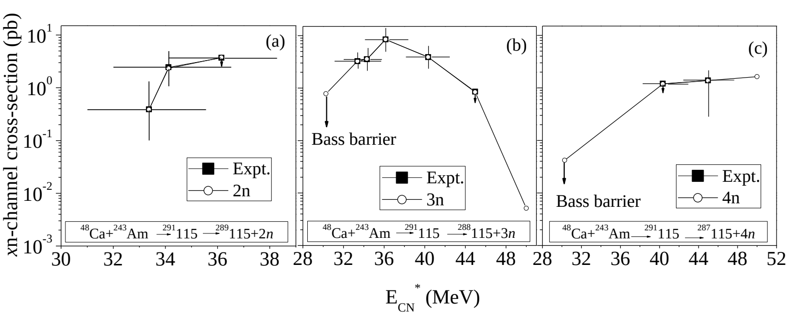


**Figure 2.** Experimental and calculated *xn* -cross-sections as a function of $E_{CN}$, and the predicted $\sigma_{3n}$ and $\sigma_{4n}$ values at extrapolated 30.28 MeV (bass barrier) and 50 MeV energies.

Fig. 2 shows a comparison of the DCM calculated *x*n-channel cross-sections of $^{243}Am+^{48}Ca$ reaction with the experimental data [1]. A nice fitting is obtained for all the channels, at different excitation energies. In addition, the 3*n* and 4*n* cross-section are also predicted at 30.28 MeV (=$B_{Bass}$; Bass barrier energy) and 50 MeV, extrapolating the neck-length parameter $\Delta R$ by following the procedure given in

Ref. [4]. The predicted 2*n* channel cross-sections are not shown as they are negligible at these extrapolated ΔR values.
In our previous work [4], the half-lives of α-decay chains of $^{291}115^*$ were calculated by considering the decaying fragments as deformed ones. In order to check the role of deformations on α-decay half-lives, we have again fitted the experimental data [1] by considering both the residual and daughter nuclei as spherical nuclei. Fig. 3 shows that for a best fit to data, both the spherical and $\beta_2$-deformed choices require the same normalizing factor of $10^4$. It is relevant to mention here that, in going from deformed to spherical case, the penetration probability shows enhancement in its magnitude whereas the preformation probability decreases due to decreased neck-length parameter ΔR (with in the range of nuclear proximity ~2 fm).

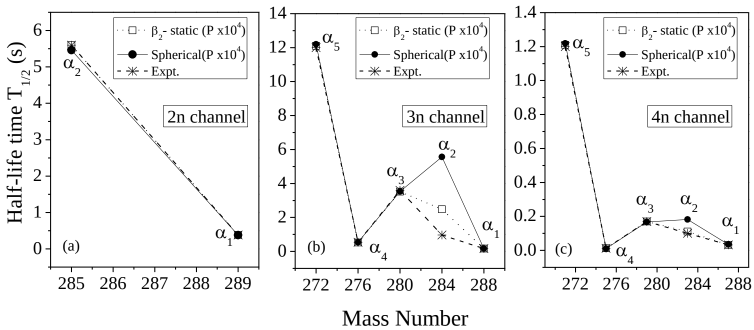


**Figure 3.** Experimental and PCM calculated half-lives of α-decay chains from (a) 2*n*- (b) 3*n*- and (c) 4*n*-decay channel of $^{291}115^*$ formed in $^{243}Am+^{48}Ca$, using spherical and deformed considerations.

## 4 Summary

The decay of $^{291}115^*$, formed in $^{243}Am+^{48}Ca$ reaction, is studied by using the dynamical cluster-decay model (DCM). The calculated *x*n evaporation residue (ER) cross-sections in $E_{CN}$=31-47 MeV range give nice comparisons with data. For 2*n* decay, the spherical case of fragments prefers symmetric fission; whereas the same for deformed choice gives asymmetric peaks in heavy fragment mass region.
The half-lives of α-decay chains are calculated by using the preformed cluster model (PCM) with spherical fragments and compared with deformed case and experimental data [1]. The penetration probability of decay fragments increase while preformation probability decrease, due to decreased magnitude of ΔR, in treating fragments as spherical rather than deformed.

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