New approach to α-decay chains in Superheavy Elements: Inclusion of temperature dependence in decay half-lives

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Introduction

During the past few years, several experimental and theoretical works have been devoted to the understanding of formation of superheavy nuclei (SHN) and their α-decay half-lives. In a recent work [1], half-lives of

α-decay chains of $^{287-289}115^*$ were calculated by some of us and collaborators by using the Preformed Cluster Model (PCM) where fragments are considered to be in ground state (T=0), like in spontaneous α-decay. The calculated half-lives were found to agree with experimental data, only within a constant empirical factor of 10^4. However, the decay-product (residue) after xn emission, i.e., the SHN produced has a recoil energy E_R associated with it before the α-decay chain starts. This calls for the possibility of including temperature T-effects in the α-decay of SHN, and hence, instead of PCM, using the Dynamical cluster-decay model (DCM) for ℓ=0 case. This is what we do here in this work.

Furthermore, a look at the binding energy curve shows that the targets ^{237}Np, ^{243}Am, ^{245}Cm, ^{249}Bk, and ^{249}Cf, used to synthesize SHN, are forced to undergo fusion reaction whereas they actually have the tendency to undergo fission, thereby moving the resulting SHN to a region of even lower binding energy per nucleon and hence greater instability. In view of this observation, the decay pattern of none of the SHN, so synthesized, follow any of the four radioactive decay series, thereby emphasizing the fact that the decay process is not that of natural radioactivity, but a "hot" (T$\neq$0) process at ℓ=0.

In the present work, we analyze the α-decay of $^{288}115^*$, formed via hot fusion reaction ^{243}Am+^{48}Ca after 3n emission [2], by using the DCM (ℓ=0 case) with deformations included up to β_2 and hot "optimum" orientations of nuclei. The synthesized SHN, before the α-decay process occurs, possess a recoil energy E_R=7-16 MeV, which acts like the $E_{c.m.}$ in a reaction. We find that, unlike the PCM, no correcting factors are needed in the DCM. This is apparently due to the temperature effects included in DCM.

The Model

In DCM (ℓ=0) or, equivalently, PCM (T$\neq$0), the decay constant/ half-life time is defined as [1, 3]

$$\lambda = P_0 \nu_0 P, \qquad T^{\frac{1}{2}} = \frac{ln2}{\lambda}. \tag{1}$$

where P_0 and P are, respectively, the preformation and penetration probability, calculated at $R = R_1 + R_2 + \Delta R$ for T-dependent potentials $V_R(\eta, T)$ and $V_\eta(R, T)$. Here, $\eta = (A_1 - A_2)/(A_1 + A_2)$, the mass asymmetry. The assault frequency for radius of nucleus R_0,

$$\nu_0 = velocity/R_0 = \frac{(2E_2/\mu)^{1/2}}{R_0} \tag{2}$$

with kinetic energy of lighter fragment A_2, $E_2 = (A_1/A)Q$. Q is the Q-value of decay.

The temperature T (in MeV) is related to excitation energy E_R^* of the residue SHN,

$$E_R^* = \frac{1}{10} A T^2 - T \qquad (MeV) \tag{3}$$

where in the present case, E_R^*=E_R+Q_α where Q_α denotes the Q-value of α-decay. Here, for

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TABLE I: The DCM-calculated preformation probability P_0, penetration probability P and α-decay half life $T_\alpha^{1/2}(DCM)$ at the best fitted neck-length parameters ΔR for different E_R values during α-decay of $^{288}115^*$ at ℓ=0. The experimental $T_\alpha^{1/2}(expt.)$=$0.17^{+0.042}_{-0.028}$ s [2].

	ΔR (fm)	P_0	P	$T_\alpha^{1/2}(DCM)$ (s)
E_R=7 MeV E_R^*=17.575 MeV T=0.798 MeV	0.958	1.28×10^{-13}	8.77×10^{-9}	0.176
E_R=10 MeV E_R^*=20.575 MeV T=0.86 MeV	0.942	2.84×10^{-13}	4.11×10^{-9}	0.170
E_R=13 MeV E_R^*=23.575 MeV T=0.92 MeV	0.927	6.13×10^{-13}	1.94×10^{-9}	0.168
E_R=16 MeV E_R^*=26.575 MeV T=0.98 MeV	0.912	1.37×10^{-12}	9.01×10^{-10}	0.163

the implantation (recoil) energy E_R, we have taken the value obtained in experiments [2].

Calculations and Results

Table I shows the calculated P_0, P and α-decay half-life $T_\alpha^{1/2}$ of $^{288}115^*$ at four different T-values corresponding to recoil energies E_R spanning the measured range, for the best fitted ΔR in DCM at ℓ=0, compared with the experimental data [2]. It is clear from the table that the fits are nicely obtained with experiments, without any empirical multiplying factor. The only parameter of the model is the neck-length parameter ΔR which varies with T with in ∼5% only.

The DCM-calculated average α-decay half-life of $^{288}115^*$ are compared in Table II, with other theoretical results and experimental data. Interestingly, compared with PCM, there is no empirical factor of 10^4 in DCM. The other theoretical model calculations either over- or under-estimate the data within a factor of ∼2. Apparently, the accurate reproduction of measured decay half-life after inclusion of temperature emphasizes the credibility of the DCM for α-decay chains in SHN.

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TABLE II: DCM-calculated α-decay half-life of $^{288}115^*$, compared with experimental data and other available theoretical results.

	Ref.	$T_\alpha^{1/2}$ (s)
Expt. Value	[2]	$0.17^{+0.042}_{-0.028}$
DCM	(This Work)	0.169
PCM	[1]	0.17×10^4
DDM3Y	[4]	$0.4105^{+0.1794}_{-0.1227}$
GLDM	[5]	$0.0947^{+0.0479}_{-0.0289}$
CYEM	[6]	0.295

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