Study of Z=105, Dubnium via cold fusion reaction ^{51}V+^{208}Pb, using Dynamical Cluster-decay Model

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I. INTRODUCTION

Synthesis of Superheavy Elements (SHEs) Z $\geq$104 were carried out either in cold fusion reactions with ^{208}Pb and ^{209}Bi as target nuclei and Ti to Zn as projectiles, or in hot fusion reactions with available actinide targets bombarded with ^{48}Ca projectile. In 'cold fusion' reactions only one (or two) neutron (s) are emitted from the compound nucleus formed, and in 'hot fusion' reactions more than 2 neutrons are emitted. In this work, we present our preliminary calculations for SHE Z=105, Dubnium via ^{51}V+^{208}Pb reaction, using the dynamical cluster-decay model (DCM) [1, 2], with deformation effects up to quadrupole deformations β_{2i} and "optimum" orientations $\theta_i^{opt.}$ for coplanar (Φ=0^0) configurations. Experimental data [3] are available for excitation functions of 1n and 2n, at six excitation energies E^* ranging from 13-28 MeV. We have made the best fit of cross sections at different time scales (equivalently, different neck-length parameter ΔR) for 1n and 2n at only one excitation energy (E^*=13.1 MeV), the only parameter in DCM. For nuclear interaction potential, we use the nuclear proximity potential whose range of validity is $\sim$2 fm). For centrifugal potential, we find that, of the sticking (I_S) and non-sticking (I_{NS}) limits of moment of inertia,I_{NS} works better for this reaction.

II. METHODOLOGY

The dynamical cluster-decay model (DCM) of Gupta and collaborators [1] is based on the quantum mechanical fragmentation theory (QMFT) [4, 5], which introduces the collective coordinates of mass (and charge) asymmetries η (and η_Z) [$\eta = (A_1 - A_2)/(A_1 + A_2)$, $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$], and relative separation R, with multipole deformations up to hexadecupole $\beta_{\lambda i}$ (λ=2,3,4; i=1,2) and orientations θ_i. In terms of these coordinates, we define the compound nucleus decay or fragment's formation cross section, for ℓ partial waves, as

$$\sigma_{(A_1,A_2)} = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \quad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{1}$$

where P_0 is fragment's preformation probability, referring to η motion at fixed R-value and P, the barrier penetrability, to R motion for each η-value. Then, it follows from Eq. (1) that

$$\sigma_{ER} = \sum_{A_2=1}^{4 \text{ or } 5}\sigma_{(A_1,A_2)} \quad \text{or} \quad = \sum_{x=1}^{4 \text{ or } 5}\sigma_{xn}, \tag{2}$$

and

$$\sigma_{ff} = 2\sum_{A_2=5 \text{ or } 6}^{A/2}\sigma_{(A_1,A_2)}. \tag{3}$$

The same equation (1) is also applicable to the quasi-fission (qf) decay process, where P_0=1 for the incoming channel since the target and projectile nuclei can be considered to have not yet lost their identity. Then, for P calculated for the *incoming channel* η_{ic},

$$\sigma_{qf} = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_{\eta_{ic}}. \tag{4}$$

Thus, the DCM predicts not only the total fusion cross section σ_{fusion}, but also its constituents, the cross sections σ_{ER}, σ_{ff} and σ_{qf} ($\sigma_{fusion} = \sigma_{ER} + \sigma_{ff} + \sigma_{qf}$).

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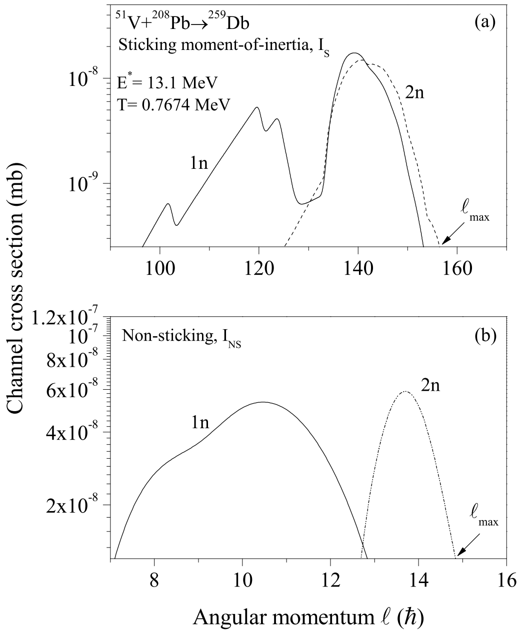

FIG. 1: (a) Variation of 1n- and 2n-decay channel cross sections vs angular momentum is completely un-physical with the sticking moment-of-inertia and (b) with non-sticking this variation is systematical.

III. CALCULATIONS AND CONCLUSIONS

In this paper, we calculate the channel cross sections at one lower excitation energy, E^*=13.1 MeV, with a particular aim to see the role of moment-of-inertia I in the rotational (ℓ)-energy term, i.e., non-ticking $I = I_{NS} = \mu R^2 + \frac{2}{5}A_1 m R_1^2(\alpha_1, T) + \frac{2}{5}A_2 m R_2^2(\alpha_2, T))$ or sticking $I = I_S = \mu R^2$ limit. Interestingly, for a best fit of ΔR to experimental data, namely, $\sigma_{1n}^{Expt.}$= 230 pb and $\sigma_{2n}^{Expt.} < 180$ pb, our calculated cross sections are, as for $I = I_{NS}$, $\sigma_{1n}^{Cal.}$= 230 pb at ΔR=1.5841 fm and $\sigma_{2n}^{Cal.}$=142 pb at ΔR=1.0968 fm for ℓ_{max}=15 $\hbar$ and, for I_S, $\sigma_{1n}^{Cal.}$= 230 pb at ΔR=2.1404 fm and $\sigma_{2n}^{Cal.}$= 180 pb at ΔR=1.463 fm, for ℓ_{max}=156 $\hbar$. Thus, in both cases, 1n channel cross section is exactly fitted, and 2n is fitted within experimental limits. Hence, both channels are shown to be pure CN decay channels. However, in Fig. 1 (a), for the case of I_S the variation of channel cross section with angular momentum turns out to be completely unphysical, which lets us discard it in favor of Fig. 1 (b) I_{NS}.

Concluding, in ^{259}Db, 1n channel and 2n channels are pure CN decay, and non-sticking is preferred over sticking.

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