

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

S. Chopra,\* Hemdeep, and Raj K. Gupta  
*Department of Physics, Panjab University, Chandigarh - 160014, INDIA*

### I. INTRODUCTION

Synthesis of Superheavy Elements (SHEs)  $Z \geq 104$  were carried out either in cold fusion reactions with  $^{208}\text{Pb}$  and  $^{209}\text{Bi}$  as target nuclei and Ti to Zn as projectiles, or in hot fusion reactions with available actinide targets bombarded with  $^{48}\text{Ca}$  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  $^{51}\text{V} + ^{208}\text{Pb}$  reaction, using the dynamical cluster-decay model (DCM) [1, 2], with deformation effects up to quadrupole deformations  $\beta_{2i}$  and “optimum” orientations  $\theta_i^{opt}$  for coplanar ( $\Phi=0^0$ ) 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  $\Delta R$ ) 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 col-

lective coordinates of mass (and charge) asymmetries  $\eta$  (and  $\eta_Z$ ) [ $\eta = (A_1 - A_2)/(A_1 + A_2)$ ,  $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$ ], and relative separation R, with multipole deformations up to hexadecupole  $\beta_{\lambda i}$  ( $\lambda=2,3,4; i=1,2$ ) and orientations  $\theta_i$ . In terms of these coordinates, we define the compound nucleus decay or fragment’s formation cross section, for  $\ell$  partial waves, as

$$\sigma_{(A_1, A_2)} = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell_{max}} (2\ell + 1) P_0 P; \quad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

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

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

and

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

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*  $\eta_{ic}$ ,

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

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

\*Electronic address: chopra.sahila@gmail.com

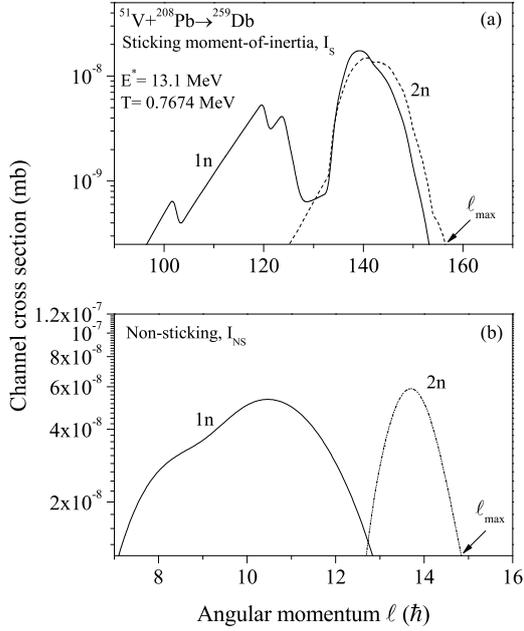


FIG. 1: (a) Variation of 1n- and 2n-decay channel cross sections vs angular momentum is completely un-physical with the sticking moment-of-inertia and (b) with non-sticking this variation is systematical.

### 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 ( $\ell$ )-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  $\Delta R$  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  $\Delta R = 1.5841$  fm and

$\sigma_{2n}^{Cal.} = 142$  pb at  $\Delta R = 1.0968$  fm for  $\ell_{max} = 15 \hbar$  and, for  $I_S$ ,  $\sigma_{1n}^{Cal.} = 230$  pb at  $\Delta R = 2.1404$  fm and  $\sigma_{2n}^{Cal.} = 180$  pb at  $\Delta R = 1.463$  fm, for  $\ell_{max} = 156 \hbar$ . 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  $^{259}\text{Db}$ , 1n channel and 2n channels are pure CN decay, and non-sticking is preferred over sticking.

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