Synthesis of Z=108 $^{269-271}$Hs nuclei: Entrance channel effects and role of double-magicity of ^{48}Ca beam

Niyti[1*] and Raj K. Gupta[2]
[1]*Department of Physics, Kurukshetra University, Kurukshetra-134119, INDIA and*
[2]*Department of Physics, Panjab University, Chandigarh-160014, INDIA*

Introduction

The macro-microscopic model, as well as self-consistent mean-field calculations that also consider deformed nuclear shapes, predicted deformed shell closures at Z=108 and N=162 [1], creating a region of enhanced stability halfway between the heaviest nuclides found on earth and the predicted island of stability around Z=114, 120 or 126, N=172 or 184. These predictions are now confirmed [2].

Z=108 Hassium nucleus was first studied in the reaction ^{248}Cm(^{26}Mg,4n/5n)^{270,269}Hs [3] at GSI (Darmstadt) through 4n and 5n decay channels, which was later [4] extended also to 3n exit channel. A similar complete measurement of evaporation residues was later reported [5] for the fusion reaction ^{238}U(^{36}S,5-3n)$^{269-271}$Hs. More recently, ^{226}Ra+^{48}Ca was used to synthesize the doubly-deformed magic nucleus ^{270}Hs [2]. The suitability of using ^{48}Ca projectile for the synthesis of superheavy elements (SHEs) has been shown repeatedly in the production of Z=112-118 nuclei.

Here, we concentrate on the entrance channels ^{226}Ra+^{48}Ca and ^{248}Cm+^{26}Mg [2–4], for the synthesis of Hs nucleus by individual light-particle (n=3,4,5) decay channels, on the basis of the Dynamical Cluster-decay Model (DCM) of Gupta and collaborators (see, e.g., [6, 7] and earlier references therein). In DCM, the deformation effects are included upto β_2, with the 'hot' optimum orientations. The DCM is a one parameter model, and, in this study, we have tried to analyze the significance of using ^{48}Ca as a projectile for synthesiszing SHEs.

*Electronic address: sharmaniyti@gmail.com

The Model

In DCM, the compound nucleus (CN) decay cross-section in terms of partial waves is

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \quad k=\sqrt{\frac{2\mu E_{cm}}{\hbar^2}} \quad (1)$$

where, $\mu = [A_LA_H/(A_L+A_H)]m$ is the reduced mass and $E_{c.m.}$, the center of mass energy. ℓ_{max}, the maximum angular momentum, is fixed for the light particles (LPs) cross-section $\sigma_{LPs}\to 0$. The preformation probability P_0 is the solution of stationary Schrödinger equation in $\eta = (A_H - A_L/(A_H + A_L)$, such that $P_0(A_i) \propto \mid \psi(\eta(A_i)) \mid^2$. It contains the structure information of compound nucleus via the fragmentation potential,

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

used in stationary Schrödinger equation. Here, V_{LDM} is the T-dependent liquid drop energy and δU, the "empirical" shell corrections. The T-, $\beta_{\lambda i}-$ and θ_i-dependent proximity V_P, Coulomb V_C and angular momentum-dependent potential V_l are [6]

$$V_P(s_0(T)) = 4\pi\bar{R}(T)\gamma b(T)\Phi(s_0(T)) \quad (3)$$

$$V_C = \frac{Z_1Z_2e^2}{R} + 3Z_1Z_2e^2\sum_{\lambda,i=1,2}\frac{R_i^\lambda(\alpha_i,T)}{(2\lambda+1)R^{\lambda+1}} \times Y_\lambda^{(0)}(\theta_i)\Big[\beta_{\lambda i}+\frac{4}{7}\beta_{\lambda i}^2Y_\lambda^{(0)}(\theta_i)\Big], \quad (4)$$

$$V_l = \frac{\hbar^2\ell(\ell+1)}{2I_s}. \quad (5)$$

Table 1: Comparison of experimental and calculated σ_{xn}, x=3-5, with fitted ΔR at E$^*\approx$ 40MeV.

Target-projectile combination used	No. of neutrons emitted	Cross-section (pb) Experimental	Calculated	ΔR (fm)
^{248}Cm+^{26}Mg	3n	$1.38^{+1.75}_{-0.85}$	1.41	1.374
	4n	$3.0^{+2}_{-1.5}$	3.07	1.642
	5n	$0.72^{+1.54}_{-0.59}$	0.729	1.836
^{226}Ra+^{48}Ca	4n	16^{+13}_{-7}	16.4	1.618

with the shortest distance s_0 giving compact θ_{ci}. P in Eq. (2) is the WKB integral, with first turning point $R_a(\eta, T) = R_1 + R_2 + \Delta R(T)$; R_i are radius vectors of the two nuclei and $\Delta R(T)$, a parameter that assimilates the neck formation effects, constant for all the fragments at a given excitation energy.

Calculations and Results

We consider ^{248}Cm+^{26}Mg and ^{226}Ra+^{48}Ca hot-fusion reactions at E^*=40 MeV, where $3n$, $4n$ and $5n$ emission data are from [2–4]. Note, the two target-projectile (t,p) combinations are, respectively, the deformed+deformed and deformed+spherical nuclei, forming the same CN ^{274}Hs*.

Table 1 and Fig. 1 show a comparison between the experimental and DCM-calculated σ_{xn}, x=3-5n, from ^{274}Hs* at a fixed E^*=40 MeV for both the entrance channels. Clearly, the experimental data are reproduced within one parameter ΔR fitting. Knowing that asymmetric t-p combinations are more suitable for the synthesis of new/ SHEs (lower interaction barrier and larger interaction radius [8]), ^{248}Cm+^{26}Mg should give a higher cross-section at any given E^*, compared to that for ^{226}Ra+^{48}Ca. However, Fig. 1 shows that, contrary to our expectations, ^{248}Cm+^{26}Mg has lower σ_{xn}, than ^{226}Ra+^{48}Ca. Apparently, this is because of the double magicity of spherical ^{48}Ca nucleus. Also, out of three isotopes produced, ^{270}Hs has the highest cross-section for the apparent reason of being a double deformed-magic nucleus.

Acknowledgments

Work supported by the DST, Govt. of India, under INSPIRE Faculty scheme.

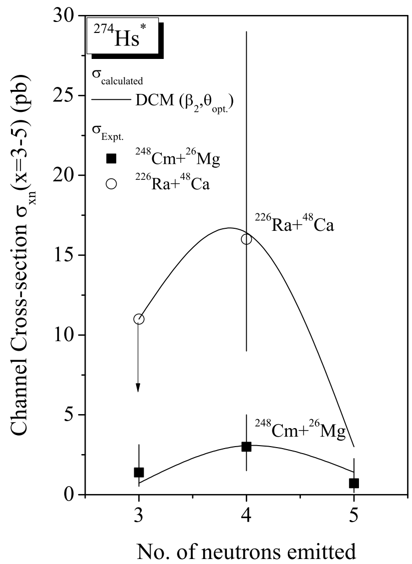

FIG. 1: The experimental and DCM calculated xn cross-sections for two different entrance channels.

References

[1] Z. Patyk and A. Sobiczewski, Nucl. Phys. A **533**, 132 (1991).

[2] Yu.Ts. Oganessian, *et al.*, Phys. Rev. **C 87**, 034605 (2013).

[3] J. Dvorak, *et al.*, Phys. Rev. Lett. **97**, 242501 (2006).

[4] J. Dvorak, *et al.*, Phys. Rev. Lett. **100**, 132503 (2008).

[5] R. Graeger, *et al.*,Phys. Rev. **C 81**, 061601(R) (2010).

[6] R.K. Gupta, *et al.*, Phy. Rev. C **70**, 034608 (2004).

[7] Niyti, *et al.*, J. Phys. G: Nucl.Part. Phys. **37**, 115103 (2010).

[8] R.K. Gupta, *et al.*, Phys. Rev. C **73**, 054307 (2006).