Synthesis of superheavy element Z=122 via hot fusion reactions

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Introduction

The study of Superheavy Elements (SHEs) has become the subject of strong interest both for experimental and theoretical research. The hot fusion reactions have been used as the tool to study the SHEs. We study here the SHE Z=122 with mass A=306 using the Dynamical cluster-decay model (DCM), the system that has been studied experimentally [1] via two hot-fusion reactions ^{58}Fe+^{248}Cm→^{306}122* and ^{64}Ni+^{242}Pu→^{306}122*, only at one excitation energy E^*=33 MeV. Experimentally, data is available for fusion-fission (ff) cross section σ_{ff} and quasi-fission (qf) cross section (σ_{qf}), only at one E^*=33 MeV (equivalently, compound nucleus (CN) center-of-mass energy $E_{c.m.}$=263.4 MeV for Fe-induced and 281.2 MeV for Ni-induced reaction).

Heavy-ion reactions at below barrier energies give rise to highly excited compound nuclear systems that carry large angular momentum, and hence decay by emitting neutrons or multiple light particles (LPs: A≤4, Z≤2, like n, p, α), and their heavier counterparts and γ-rays, termed the evaporation residue (ER), and ff consisting of near-symmetric and symmetric fission fragments (nSF and SF)(A/2)±20. Using the DCM, we have calculated the best fitted values of σ_{ff} and σ_{qf} cross sections, with inclusion of deformation effects up to quadrupole deformations β_{2i} and "optimum" orientations $\theta_i^{opt.}$, within coplanar configuration (Φ=0^0).

We do not have the measured data for ERs, but we have also calculated the ER cross section σ_{ER} in our above use of the DCM. The only parameter of the model is the neck-length parameter, which varies smoothly with temperature of the CN, and its value remains within the range (∼2 fm) of validity of proximity potential. σ_{ER} is predicted to be of the order of attobarn (∼ 10^{-15} mb), depending on the choice of neck-length parameter for ER and ff region. In an earlier study [2] of using the Langevin approach, the authors have shown the calculated number for ERs of the same reactions to be ∼23 fb at E^*=53 MeV, which is a small number, and our calculated cross section is smaller than this value. A brief report of this work was made at the 2016 Chandigarh Science Congress (CHASCON) [3].

The Dynamical cluster-decay model (DCM)

The dynamical cluster-decay model (DCM) of Gupta and collaborators [4, 5] is based on the dynamical or quantum mechanical fragmentation theory (QMFT), which itself is based on the collective coordinates of mass (and charge) asymmetries η (and η_Z) [η=(A$_1$-A$_2$)/(A$_1$+A$_2$), η_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 (CN) decay cross section for ℓ partial waves as the CN decay/ fragments-formation cross section for each pair of exit/ decay channel as

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

where P_0 is fragment preformation probability, referring to η motion at fixed R-value and P, the barrier penetrability, to R motion for each η-value, both dependent on T and ℓ. The

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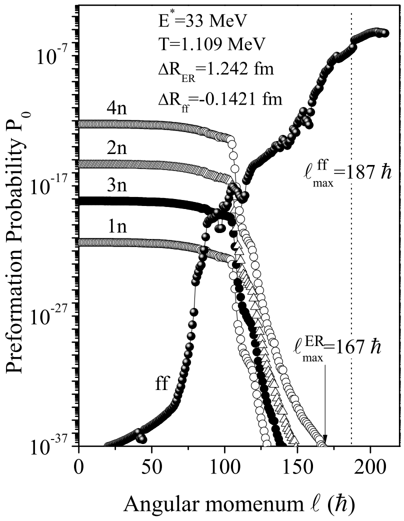

FIG. 1: Maximum angular momentum fixed for ERs, as $\sigma_{ER} \rightarrow 0$ and for ff, as σ_{ff} goes to near maximum.

reduced mass $\mu = mA_1A_2/(A_1 + A_2)$ with m as the nucleon mass and ℓ_{max} is the maximum angular momentum, defined for light-particles ER cross section $\sigma_{ER} \rightarrow 0$ and for fission its near maximum cross section value (see Fig. 1), Then, it follows from Eq. (1) that

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

and

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

The above equation (1) is also applicable to the noncompound-nucleus (nCN) decay process, calculated here as the qf decay channel, where P_0=1 for the *incoming channel* since the target and projectile nuclei can be considered to have not yet lost their identity.

Calculations and Results

Table I shows that our DCM-calculated cross sections for fission and quasi-fission are in good agreement with the experiments, at best fitted (neck-length parameter) ΔR= -0.1421 fm and 1.007 fm, respectively, for ff and qf. We have also calculated the ER cross section σ_{ER} at ΔR=1.242 fm, which is of the order of attobarn ($\sim 10^{-15}$ mb).

TABLE I: Cross sections for Z=122, A=306 for ff and qf at best fitted ΔR, at E^*=33 MeV, and the predicted ER cross sections.

Reaction	$\sigma_{ff}^{Cal.}$ (mb)	$\sigma_{ff}^{Expt.}$ (mb)	$\sigma_{qf}^{Cal.}$ (mb)	$\sigma_{qf}^{Expt.}$ (mb)	$\sigma_{ER}^{Cal.}$ (ab)
^{58}Fe+^{248}Cm	1.616	1.616	22.6	22.603	0.277
^{64}Ni+^{242}Pu	1.516	-	21.2	-	0.259

In future, we wish to calculate the three cross sections at more excitation energies, near and below coulomb barrier, to see the best possibility of the synthesis of Z=122, with the ER, ff, and qf decay channels.

Summary and Conclusions

Concluding, the DCM-calculated results match the experimental data for ff and qf cross sections, with the predicted numbers for ER cross sections of very small values (in attobarn). Further experimental and theoretical studies are called for ff, qf as well as the ER channels in this reaction.

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