# Study of the decay of compound nucleus $^{64}$Zn* within the Dynamical Cluster-decay Model

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## Introduction

The experimental cross-section data of the residual radionuclides produced through *xn*, *pxn* and *αpxn* channels are available from the $^{12}$C+$^{52}$Cr system at various energies ($E_{lab}$=51.5-87 MeV) [1] via complete fusion (CF) and/or incomplete fusion (ICF) processes. A theoretical description to investigate the CF/ICF reaction dynamics is reported here.

In this calculation, we have considered $^{12}$C+$^{52}$Cr reaction at $E^*_{CN}$ = 52.43 MeV using the Dynamical Cluster-decay Model (DCM) [2] based on quantum mechanical fragmentation theory (QMFT), which includes the deformation and orientation effects of the outgoing co-planar or non-coplanar decay fragments. Using this model we fitted the cross-sections for 2*n*, *p*2*n*, *p*3*n*, *αpn*, *αp*2*n*, and *αp*3*n* decay channels. The cross-sections so obtained are for the best fit of the neck-length parameter $\Delta R$. The calculations are made for quadrupole deformations ($\beta_{2i}$) together with optimum orientations $\theta_i^{opt}$ of the two nuclei lying in the same plane, i.e., coplanar nuclei ($\Phi = 0^o$).

## Methodology

The quantum mechanical fragmentation theory (QMFT)-based on Dynamical Cluster-decay Model (DCM) [3], in which the decay of excited compound nucleus is worked out in terms of the collective coordinates of mass and charge asymmetry, i.e., $\eta$ and $\eta_Z$, respectively, where $\eta=(A_1-A_2)/(A_1+A_2)$, $\eta_Z=(Z_1-Z_2)/(Z_1+Z_2)$, relative separation coordinate $R$, with deformation $\beta_{\lambda i}$ ($\lambda$=2,3,4: $i$=1,2), orientations $\theta_i$, and azimuthal angle $\Phi$ between the two nuclei. In terms of these collective coordinates, using the partial wave analysis, compound nucleus decay cross section is defined as

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P \ ;$$

where $$k = \sqrt{\frac{2\mu E_{cm}}{\hbar^2}}$$

Here, the preformation probability $P_0$ refers to $\eta$ and the penetrability $P$ refers to $R$-motion. The same formula is applicable to ICF decay process where $P_0$ =1 since the target and the projectile nuclei can be considered to have not yet lost their identity. The collective fragmentation potential $V_R(\eta,T)$, that brings the structure effects of the compound nucleus (CN) in the formalism, used for calculating preformation probability $P_0$ is given by the solution of stationary Schrödinger equation in $\eta$, at a fixed $R=R_a$, the first turning point(s) of the penetration path(s) for each $\ell$-values.

$$\left\{\frac{-\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V(\eta)\right\}\psi^{\nu}(\eta)=E^{\nu}_{\eta}\psi^{\nu}(\eta)$$

with $\nu$ = 0,1,2,3,…. referring to the ground state ($\nu$ = 0) and excited state solutions. Then, the ground state preformation probability is

$$P_0(A_i)=\left|\psi_R(\eta(A_i))\right|^2\sqrt{B_{\eta\eta}}\frac{2}{A}$$

Penetrability $P$, is given by the WKB integral

$$P=\exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_b}\left\{2\mu\left[V(R,T)-Q_{eff}\right]\right\}dR\right]$$

where, $Q_{eff}=V(R_a)$ = TKE($T$) is the effective Q-value of the decay process, $R_a$ and $R_b$ are the two turning points of WKB integral. For $\eta$-motion, the potential $V(\eta)$ used in the Schrödinger equation is the sum of liquid drop energy, shell corrections, Coulomb, nuclear proximity and $\ell$-dependent potentials.

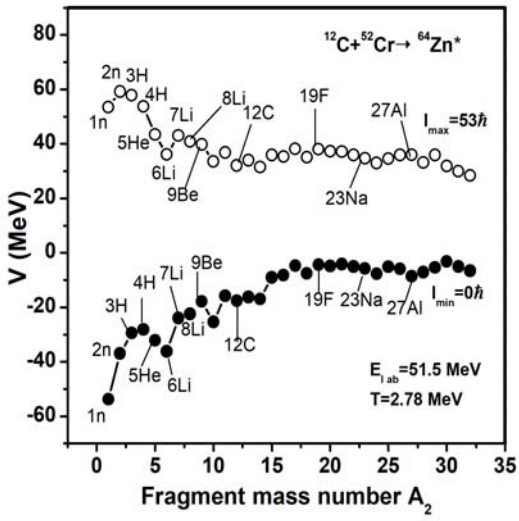


**Fig. 1**: The fragmentation potentials $V(A_2)$ for decay of $^{64}Zn^*$, plotted at $\ell_{max}$ and $\ell_{min}$ values, for best fitted $\Delta R$ values given in Table 1.

## Results

In this contribution, we are interested in studying the ICF reaction dynamics using DCM where only $\beta_{2i}$ and coplanar collisions ($\Phi$ = 0°) are included in the reaction mechanism.

Fig. 1 shows the fragmentation potential for the decay of $^{64}Zn^*$ at $E^*_{CN}$=52.43 MeV, equivalently $T$=2.78 MeV, for best-fitted $\Delta R$ to the observed data for 2*n*, *p*2*n*, *p*3*n*, *αpn*, *αp*2*n* and *αp*3*n*, equivalently 2*n*, $^3$H, $^4$H, $^6$Li, $^7$Li, and $^8$Li channels, 1*n* and $^5$He being unobserved.

**Table 1:** DCM calculated CN and ICF(≡ nCN) contributions in measured cross-section.

| Decay channel | $\Delta R$ | $\sigma_1$ (CN) | $\Delta R$ | $\sigma_2$ (nCN) |
|---|---|---|---|---|
| 1*n* | 1.0 | 9.24 | -1.02 | 0.581 |
| 2*n* | 1.75 | 10.6 | -1.06 | 1.26 |
| $^3$H | 1.5 | 0.349 | 0.349 | 208.1 |
| $^4$H | 1.5 | 0.690 | -0.7 | 16.7 |
| $^5$He | 1.0 | 0.645 | -0.6 | 5.92 |
| $^6$Li | 1.45 | 267 | 0.175 | 51 |
| $^7$Li | 1.45 | 5.59 | 0.451 | 92.21 |
| $^8$Li | 1.45 | 4.08 | -0.3 | 6.69 |

**Table 2:** Comparison between DCM calculated and measured cross sections.

| Decay channel | $\sigma^{DCM}=\sigma_1+\sigma_2$ (mb) | $\sigma^{exp}$ (mb) |
|---|---|---|
| 1*n* | 9.82 | - |
| 2*n* | 11.86 | 11.8 |
| $^3$H | 208.45 | 208.5 |
| $^4$H | 17.39 | 4.1 |
| $^5$He | 6.56 | - |
| $^6$Li | 318 | 317.9 |
| $^7$Li | 98.09 | 97.8 |
| $^8$Li | 10.77 | - |

Table 2 shows the cross-sections calculated using quadrupole deformations $\beta_{2i}$ and optimum orientations $\theta_i^{opt}$ with $\Phi$ = 0$^0$ for both CN and non-compound nuclear (nCN) contributions. We observe good agreement, though an enhancement in cross section via *p*3*n* decay channel is indicated, compared to experimental cross-section. These calculations are, however, preliminary.

## Conclusion

The DCM calculations match with the experimental data for cross-sections of 2*n*, $^3$H, $^6$Li and $^7$Li decay channels, i.e., the residues $^{62}$Zn, $^{61}$Cu, $^{58}$Co and $^{57}$Co which are then best fitted with nCN contribution wherever needed. On the other hand, we predict cross sections of decay channels 1*n*, $^5$He and $^8$Li through the theoretical calculation obtained by the DCM that is not observed in the experimental results. This calls for inclusion of higher multipole deformations and non-coplanarity degrees-of-freedom in the DCM.

## References

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