

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

Gayatri Sarkar¹, Moumita Maiti^{1*}, Sahila Chopra², Hemdeep², Pooja Kaushal², and Raj K. Gupta²

¹Department of Physics, Indian Institute of Technology, Roorkee, Roorkee - 247667, INDIA

²Department of Physics, Panjab University, Chandigarh-160014, INDIA

*email: moumifph@iitr.ac.in

Introduction

The experimental cross-section data of the residual radionuclides produced through xn , pxn and $apxn$ channels are available from the $^{12}\text{C}+^{52}\text{Cr}$ 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 $^{12}\text{C}+^{52}\text{Cr}$ 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 $2n$, $p2n$, $p3n$, apn , $ap2n$, and $ap3n$ decay channels. The cross-sections so obtained are for the best fit of the neck-length parameter ΔR . The calculations are made for quadrupole deformations (β_{2i}) together with optimum orientations θ_i^{opt} of the two nuclei lying in the same plane, i.e., coplanar nuclei ($\Phi = 0^\circ$).

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., η and η_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 θ_i , and azimuthal angle Φ between the two nuclei. In terms of these collective coordinates, using the partial wave analysis, compound nucleus decay cross section is defined as

$$\sigma = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell_{max}} (2\ell+1) P_0 P ;$$

where

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

Here, the preformation probability P_0 refers to η 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 η , at a fixed $R=R_a$, the first turning point(s) of the penetration path(s) for each ℓ -values.

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

with $v = 0, 1, 2, 3, \dots$ referring to the ground state ($v = 0$) 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, $Q_{eff} = V(R_a) = \text{TKE}(T)$ is the effective Q-value of the decay process, R_a and R_b are the two turning points of WKB integral. For η -motion, the potential $V(\eta)$ used in the Schrödinger equation is the sum of liquid drop energy, shell corrections, Coulomb, nuclear proximity and ℓ -dependent potentials.

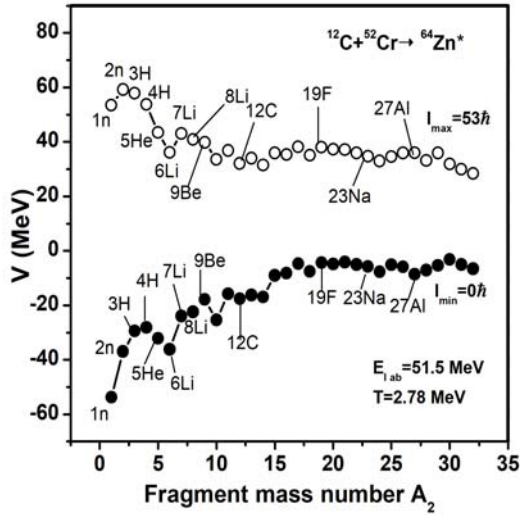


Fig. 1: The fragmentation potentials $V(A_2)$ for decay of $^{64}\text{Zn}^*$, plotted at ℓ_{\max} and ℓ_{\min} values, for best fitted ΔR values given in Table 1.

Results

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

Fig. 1 shows the fragmentation potential for the decay of $^{64}\text{Zn}^*$ at $E_{\text{CN}}^* = 52.43$ MeV, equivalently $T = 2.78$ MeV, for best-fitted ΔR to the observed data for $2n$, $p2n$, $p3n$, apn , $ap2n$ and $ap3n$, equivalently $2n$, ^3H , ^4H , ^6Li , ^7Li , and ^8Li channels, $1n$ and ^5He being unobserved.

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

Decay channel	σ_1		σ_2	
	ΔR	(CN)	ΔR	(nCN)
$1n$	1.0	9.24	-1.02	0.581
$2n$	1.75	10.6	-1.06	1.26
^3H	1.5	0.349	0.349	208.1
^4H	1.5	0.690	-0.7	16.7
^5He	1.0	0.645	-0.6	5.92
^6Li	1.45	267	0.175	51
^7Li	1.45	5.59	0.451	92.21
^8Li	1.45	4.08	-0.3	6.69

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

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

Table 2 shows the cross-sections calculated using quadrupole deformations β_{2i} and optimum orientations θ_i^{opt} with $\Phi = 0^\circ$ for both CN and non-compound nuclear (nCN) contributions. We observe good agreement, though an enhancement in cross section via $p3n$ 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 $2n$, ^3H , ^6Li and ^7Li 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 $1n$, ^5He and ^8Li 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

- [1] F.K. Amanuel et al., Phys. Rev. C **84**, 024614 (2011).
- [2] R. K. Gupta, Lecture Notes in Physics 818, *Clusters in Nuclei*, Ed. C. Beck, **1** (2010) 223.
- [3] S. Chopra et al., Phys. Rev. C **93**, 024603 (2016).