Decay of ^{202}Po* using the dynamical cluster-decay model with higher-multipole deformations and non-coplanarity included

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Introduction

Recently, compound nucleus (CN) ^{202}Po*, formed in reaction ^{48}Ca+^{154}Gd, decaying to ground state (g.s.) of ^{198}Po by the emission of 4n and to meta-stable states (m.s.) ^{199m}Po and ^{197m}Po via 3n and 5n emissions at various CN excitation energies E^*_{CN} [1], has been analyzed within the Dynamical Cluster-decay Model (DCM) [2] for quadrupole deformed (β_{2i}) and optimum oriented (θ_i^{opt}), co-planar (in the same plane, $\Phi = 0^o$) nuclei. Interestingly, the two different kinds of decays of the same CN are governed by different CN decay processes, i.e., the g.s. to g.s. decay of ^{202}Po* requiring quasi-fission (qf)-like non-compound nucleus (nCN) decay contribution and the g.s. to m.s. decay of ^{202}Po* being a pure CN decay (σ_{nCN}=0).

In the present work, we investigate effects of inclusion of higher multipole deformations (β_{3i}, β_{4i}), with corresponding "compact" orientations (θ_{ci}), and non-coplanarity degree-of-freedom (Φ_c) on the pure CN decay cross sections of (3n, 5n) decay-channels observed in the g.s. to m.s. decay of ^{202}Po*, and the nCN decay cross section of 4n decay-channel in the g.s. to g.s. decay of ^{202}Po*, and its comparison with the already studied ^{220}Th* CN within the DCM by one of us [3] where, out of the measured 3n-5n decay channels observed in the g.s. to g.s. decay of ^{220}Th*, the 3n- and 5n-decays are always the pure CN decays while the 4n-decay is mainly of the nCN content, and further see whether, like for ^{220}Th*, variation of $\sigma_{4n}^{nCN}(E^*_{CN})$ is CN-specific or not.

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Methodology

The quantum mechanical fragmentation theory (QMFT)-based DCM [4], for the decay of hot CN with temperature T and angular momentum ℓ, is worked out in terms of the collective coordinates of mass (and charge) asymmetries $\eta = (A_1 - A_2)/(A_1 + A_2)$ [and $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$] and relative separation coordinate R, having multipole deformations $\beta_{\lambda i}$ (λ=2,3,4; i=1,2), orientations θ_i and the azimuthal angle Φ. In terms of these coordinates, for ℓ partial waves, we define for each fragmentation (A_1, A_2), the CN decay/ or formation cross section as

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

P_0 is the preformation probability referring to η motion at a fixed R and P, the penetrability to R motion for each η (given by WKB integral), both dependent on ℓ and T. The same formula is applicable to the nCN 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. The collective fragmentation potential $V_R(\eta, T)$ is calculated according to the Strutinsky renormalization procedure ($B = V_{LDM} + \delta U$, B the binding energy), as

$$\begin{aligned} V_R(\eta,T) = &-\sum_{i=1}^{2} B(A_i,\beta_{\lambda i},T)] \\ &+V_P(R,A_i,\beta_{\lambda i},\theta_i,T) + V_C(R,Z_i,\beta_{\lambda i},\theta_i,T) \\ &+V_\ell(R,A_i,\beta_{\lambda i},\theta_i,T) \end{aligned} \tag{2}$$

which brings in the structure effects of the CN. The kinetic energy is via hydrodynamical masses.

TABLE I: DCM calculated decay channel cross sections for g.s. to g.s. and g.s. to m.s. decays of ^{202}Po* at E^*_{CN}=53.61 MeV, with inclusion of higher multipole deformations for $\Phi=0^o$ and $\Phi_c \neq 0^o$, compared with the case of β_{2i}, θ_i^{opt}, $\Phi=0^o$ calculation [2] and experimental data [1].

g.s. to g.s. decay of ^{202}Po* via 4n							
	$\Phi=0^o$				$\Phi_c \neq 0^o$		
	β_{2i},θ_i^{opt}		β_{2i}-β_{4i},θ_{ci}		β_{2i}-β_{4i},θ_{ci}		
xn	σ_{xn}^{CN} (mb)	σ_{xn}^{nCN} (mb)	σ_{xn}^{CN} (mb)	σ_{xn}^{nCN} (mb)	σ_{xn}^{CN} (mb)	σ_{xn}^{nCN} (mb)	$\sigma_{xn}^{Expt.}$ (mb)
1n	10^{-7}	-	10^{-7}	-	10^{-7}	-	-
2n	10^{-13}	-	10^{-13}	-	10^{-12}	-	-
3n	10^{-21}	-	10^{-21}	-	10^{-21}	-	-
4n	1.03	1.87	1.06	1.84	1.11	1.79	2.9±0.5
5n	10^{-29}	-	10^{-29}	-	10^{-29}	-	-
g.s. to m.s. decay of ^{202}Po* via 3n,5n							
1n	10^{-3}	-	10^{-3}	-	10^{-3}	-	-
2n	10^{-8}	-	10^{-7}	-	10^{-8}	-	-
3n	1.10	0	1.10	0	1.10	0	1.1±0.2
4n	10^{-24}	-	10^{-25}	-	10^{-24}	-	-
5n	0.86	0.14	0.90	0.10	1.00	0	1.0±0.2

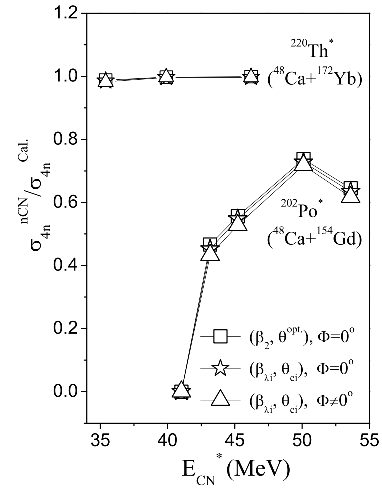

FIG. 1: A comparison between CN ^{202}Po* and ^{220}Th* for the variation of $\sigma_{4n}^{nCN}/\sigma_{4n}^{Cal.}$ (=$\sigma_{4n}^{nCN}/(\sigma_{4n}^{CN}+\sigma_{4n}^{nCN})$) with E^*_{CN} for g.s. to g.s. decay.

Calculations and Results

In the g.s. to g.s. decay of ^{202}Po*, the nCN content σ_{4n}^{nCN}, in the observed 4n channel, with (β_{2i}-alone, θ_i^{opt}, $\Phi=0^o$) remains (nearly) the same irrespective of adding or not adding higher-multipole deformations in either $\Phi = 0^o$ or $\Phi_c \neq 0$ configurations, shown here for E^*_{CN}=53.61 MeV, equivalently, T=1.65 MeV (Table I). However, the (3n, 5n) decay channels in the g.s. to m.s. decay fit nearly exactly, i.e., are the pure CN decay cross-sections, of which 5n improves successively in going from (β_{2i}-alone,θ_i^{opt}, $\Phi=0^o$) to (β_{2i}-β_{4i},θ_{ci}, $\Phi=0^o$) and then to (β_{2i}-β_{4i},θ_{ci}, $\Phi_c \neq 0$) configuration where it gets exactly fitted to the experimental cross section. A comparative study of g.s. to g.s. decay of ^{202}Po* CN with another radioactive ^{220}Th* CN formed via ^{48}Ca+^{172}Yb reaction shows that for both the compound nuclei, the nCN content in the 4n decay channel is independent of adding or not adding higher-multipole deformations β_{3i}, β_{4i} in coplanar ($\Phi=0^o$) or non-coplanar ($\Phi \neq 0^o$) configurations (see FIG. 1), which is possibly due to the same projectile (^{48}Ca), and target nucleus belonging to the same class of strongly deformed rare-earth mass region, for both the reactions. On the other hand, the fractional σ_{4n}^{nCN}, i.e., $\sigma_{4n}^{nCN}/\sigma_{4n}^{Cal.}=\sigma_{4n}^{nCN}/(\sigma_{4n}^{CN}+\sigma_{4n}^{nCN})$ as a function of E^*_{CN} remains nearly a constant ($\simeq$0.95) for ^{220}Th* CN while this ratio varies from zero to a maximum of ~0.7 for ^{202}Po* CN. Hence, the nCN cross section σ_{nCN}-content in σ_{fusion} is different for different compound nuclei and is thus CN-specific.

References

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