Role of asymmetry and magicity of nuclei in formation and decay of ^{220}Th* compound nucleus

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Introduction

The effect of entrance channel mass asymmetry and shell structure (magicity) for different reaction channels ^{16}O+^{204}Pb, ^{48}Ca+^{172}Yb and ^{40}Ar+^{180}Hf, leading to the same compound nucleus (CN) ^{220}Th*, is studied within the Dynamical Cluster-decay Model (DCM) [1]. The experimental data for evaporation residue (ER) excitation function is taken from Refs. [2–4]. The only parameter of the model, neck-length parameter ΔR, varies smoothly with the excitation energy E^* of the system and is used to best fit the experimental data.

Methodology

The DCM for the decay of hot and rotating CN is worked out in terms of the collective coordinates of mass (and charge) asymmetry 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 coordinate R, with quadrupole deformations β_{2i}; i=1,2 and "optimum" orientations $\theta_i^{opt.}$. In terms of these coordinates, for ℓ partial waves, the CN decay cross section for each fragmentation is defined as

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

where P_0 is preformation probability referring to η motion and P, the penetrability, to R motion, both dependent on angular momentum ℓ and temperature T. μ is reduced mass. ℓ_{max} is defined for light particle evaporation residue cross section $\sigma_{ER}\rightarrow$0. The same formula is applicable to the noncompound-nucleus (nCN) decay process, calculated as the quasi-fission (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.

TABLE I: The DCM calculated ER cross section $\sigma_{ER}^{Cal.}$ (=$\sum_{x=1}^{5}\sigma_{xn}$) for a fixed neck-length ΔR.

Reactions A$_1$+A$_2$	E^* (MeV)	ΔR (fm)	$\sigma_{ER}^{Cal.}$ (mb)	σ_{ER}^{Expt} (mb)
^{16}O+^{204}Pb	34.95	1.6244	4.06	4.06
(η=0.854)	41.93	1.5863	1.91	1.91
^{40}Ar+^{180}Hf	35.64	1.2634	6.15×10^{-3}	6.159×10^{-3}
(η=0.636)	41.37	1.3524	36.3×10^{-3}	36.309×10^{-3}
^{48}Ca+^{172}Yb	35.4	1.3804	77.0×10^{-3}	77.0×10^{-3}
(η=0.563)	39.9	1.4052	107.3×10^{-3}	107.30×10^{-3}

Calculations and Results

A. Formation of the CN ^{220}Th*

To study the role of asymmetry and magicity in the formation of CN ^{220}Th* through ^{16}O+^{204}Pb, ^{48}Ca+^{172}Yb and ^{40}Ar+^{180}Hf entrance channels, we best fit the ER cross section, given as sum of all decay channels 1n-5n ($\sigma_{ER}^{Cal.}$=$\sum_{x=1}^{5}\sigma_{xn}$) for a fixed ΔR at a given E*, since the CN is formed at a fixed relative separation R (R=R$_1$+R$_2$+ΔR).

Table I presents our results for the three different entrance channels at two E*'s. The fitted ΔR's lie within the proximity potential range of ∼2 fm. We notice that ΔR is larger (reaction time shorter) for the most asymmetric system having magic structure of nuclei. Thus, for the three reactions considered, the most asymmetric ^{16}O+^{204}Pb reaction has

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TABLE II: The DCM calculated 3n, 4n and 5n decay channel cross sections of ^{220}Th* at E* ≈46 MeV, with $\sigma^{Cal.1}$ as CN, $\sigma^{Cal.2}$ as nCN contributions, and their sum $\sigma_{ER}^{Cal.}$ compared with experimental data.

			DCM-Cal.1 (CN-contribution)		DCM-Cal.2 (nCN contribution)			
Reaction	Decay-channel	$\sigma_{ER}^{Expt.}$ (μb)	ΔR (fm)	$\sigma^{Cal.1}$ (μb)	σ_{nCn}^{Emp} (μb)	ΔR (fm)	$\sigma^{Cal.2}$ (μb)	$\sigma_{ER}^{Cal.}$ (μb)
^{16}O+^{204}Pb	1n, 2n	-	1	$\sim 10^{-3}$	-	-	-	$\sim 10^{-3}$
	3n	-	2.2	4.37×10^2	-	1.2	2.83×10^1	4.65×10^2
	4n	-	2.65	0.348	-	1.384	6.78×10^2	6.78×10^2
	5n	-	2.3	3.21×10^{-2}	-	1.2	1.12×10^1	1.12×10^1
	σ_{ER}	1.154×10^3		4.37×10^2	7.17×10^2		7.17×10^2	1.154×10^3
^{48}Ca+^{172}Yb	3n	22.4±3.4	2.037	22.3	-	0.7	7.61×10^{-4}	22.3
	4n	86.8±6.1	2.7	0.142	86.688	1.2369	86.65	86.792
	5n	8.5±1.4	2.31	8.5	-	0.6	5.76×10^{-6}	8.5
^{40}Ar+^{180}Hf	3n	1.971	1.8045	1.97	-	0.7	$4.707\times10^{-4}7$	1.97
	4n	34.6005	2.7	0.118	34.482	1.2052	34.470	34.588
	5n	4.825	2.3	4.825	-	0.6	2.81×10^{-6}	4.825

largest ΔR with largest ER cross section, followed by ^{48}Ca+^{172}Yb, though ^{40}Ar+^{180}Hf reaction has larger asymmetry but a non-magic structure.

B. Decay of the CN ^{220}Th*

Table II shows the comparison of experimental and DCM-calculated xn-decay cross sections σ_{xn}, x=3-5, from ^{220}Th* at a fixed E* ≈46 MeV for the chosen three entrance channels ^{16}O+^{204}Pb, ^{40}Ar+^{180}Hf, ^{48}Ca+^{172}Yb. For ^{16}O+^{204}Pb reaction, since the decay channels are not observed, we try to predict the contribuing channels for a best fit of ΔR to give σ_{ER} due to both CN and nCN effects at a fixed E*. We note from Table II and Fig. 1 that the channel cross section is larger for the doubly magic reacting nuclei, the larger one being for ^{16}O+^{204}Pb with larger mass asymmetry, i.e., for all xn-decay channels, the cross section is largest for the most asymmetric, magic nuclei. We further notice that 4n-decay channel, resulting in ^{216}Th, has the largest cross section due to neutron magic number N=126.

Concluding, both the mass asymetry and magicity of nuclei are important for the formation and decay of CN.

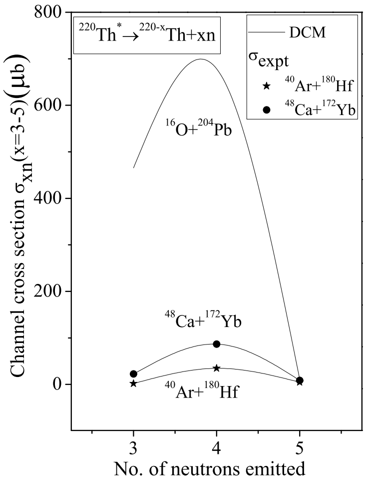

FIG. 1: The DCM calculated xn cross sections compared with experimental data for different entrance channels at E*≈ 46 MeV.

References

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