On the missing 1n contribution in ^{12}C+^{93}Nb$\rightarrow^{105}$Ag* reaction at below barrier energies

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Introduction

In a recent experiment [1], the excitation functions (EFs) of various evaporation residues were measured in the decay of compound nucleus ^{105}Ag* formed in ^{12}C+^{93}Nb reaction at below barrier energies. The observed decay products are the heavy residues whose complementary fragments are the light particles (LPs, with mass$\leq$4) and intermediate mass fragments (IMFs, 4$\leq$mass$\leq$13). The data is compared with statistical model code PACE2, which gives the complete fusion (CF) cross-section consisting of 2n, 3n, 4n and possibly ^{4}H. The disagreement of PACE2 for heavier residues, the IMFs, is taken by the authors as signatures of incomplete fusion ICF and/or the direct reaction process, supported by their recoil range distribution measurements. The ICF consists of (complementary fragments) of ^{4,5,6}H, ^{4,5}He, ^{8}Li, ^{9,10,11}Be, ^{12}B, and ^{13}C. What is striking of the PACE2 predictions is that 1n emission is, in general, found missing (see, e.g., also Ref. [2] for ^{64}Ni+^{100}Mo reaction) whereas the dynamical cluster-decay model [3] predict the contribution due to 1n to be the largest to total evaporation residue cross-section.

In this contribution, we attempt to determine the missing 1n content of evaporation residue cross-section in the decay of ^{105}Ag* formed in reaction ^{12}C+^{93}Nb, using the dynamical-cluster decay model (DCM) [3, 4] at an illustrative lab. energy E_{Lab}=61.2 MeV ($E_{c.m.}$=54.205 MeV). It is important to stress that the study of EFs serves as a powerful tool to understand the reaction mechanism governing the collision dynamics, ranging from CF, ICF to more complex non-compound nucleus (nCN) pre-equlibrium or quasi-fission (qf) processes. Our DCM calculatons include deformation effects up to hexadecapole deformations (β_2, β_3, β_4) with compact orientations of hot fusion process, for the case of coplaner nuclei only (azimuthal angle Φ=0^0).

Dynamical cluster-decay model

The DCM of Gupta and collaborators [3, 4] is based on collective coordinates of mass (and charge) asymmetries η (and η_z) [$\eta = (A_1 - A_2)/(A_1 + A_2)$, $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$], and relative separation R, with multipole deformations $\beta_{\lambda i}$ (λ=2,3,4; i=1,2), and orientations θ_i. In terms of these coordinates, we define the compound nucleus decay cross section for ℓ partial waves as

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

where P_0 is preformation probability refering to η motion and P, the penetrability, to R motion, both dependent on ℓ (angular momentum) and T (temperature). μ is reduced mass with m as the nucleon mass. ℓ_{max} is maximum angular momentum, defined for light particle evaporation residue cross section $\sigma_{ER} \rightarrow$0. P_0 is the solution of stationary schrödinger equation in η and P is the WKB penetrability of preformed fragments. Note that P_0 imparts the important nuclear structure information which is otherwise missing in alternative statistical models. The only parameter of the model is the T dependent neck-length parameter ΔR(T), defining the first turning point $R_a = R_1(\alpha_1, T) + R_2(\alpha_2, T) + \Delta R(T)$ for the penetration P. DCM is also applied to nCN, qf process where P_0=1 since the incoming channel remains unaffected.

Table 1: Experimental and calculated channel cross-sections at $E_{c.m.}$=54.205 MeV for fitted ΔR=1.363 fm, ℓ_{max}=76 $\hbar$.

No. of neutrons emitted	Cross-section (mb) Experimental	Calculated
1n	–	75.4
2n	7.6 ± 1.4	7.6
3n	398.2 ± 46.9	0.156
4n	203.4 ± 26.4	0.0022

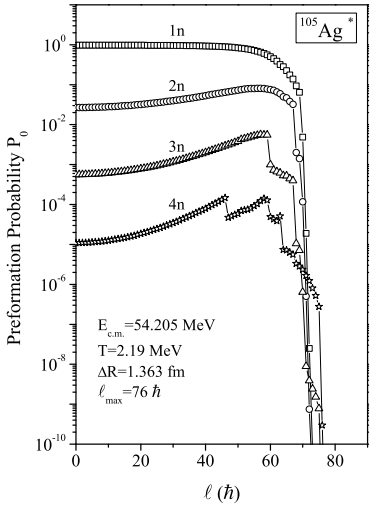

FIG. 1: Preformation probability P_0 as a function of angular momentum ℓ for xn decay of ^{105}Ag* formed in ^{12}C+^{93}Nb reaction at $E_{c.m.}$=54.205 MeV, using ΔR=1.363 fm and ℓ_{max}=76 $\hbar$.

Calculations and results

First of all, we look for the possible decay processes in ^{105}Ag* formed in ^{12}C+^{93}Nb reaction. We are interested in evaporation residue channels xn, x=2,3,4 populated by CF. Also, ^{4}H residue channel could be due to CF. Apparently, the 1n evaporation channel is not observed in this reaction.

Our calculated fragmentation potential $V(\eta)$ on DCM, for best fitted ΔR to the measured 2n cross-section, gives potential energy minima at 1n, 2n, 3n and ^{4}H, i.e. ^{4}H is energetically more favoured than 4n. Though ^{4}H could also be taken as CF product, we have replaced it by the binding energy of 4n (and the complementary heavy fragment).

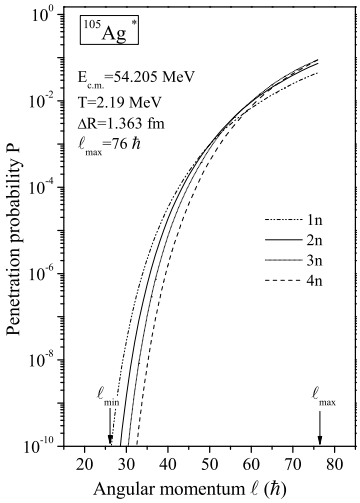

FIG. 2: Same as for Fig. 1, but for the penetrability P.

Figs. 1 and 2 show the calculated P_0 and P as a function of ℓ for xn, x=1,2,3,4 channels. Interesting enough, 1n channel competes with other three neutron channels. In fact 1n product is not only most strongly preformed, but has the largest penetrability. In other words, the σ_{1n} makes the larget contribtion to evaporation residue cross-section $\sigma_{ER} = \sum_x \sigma_{xn}$. Table 1 suggests the use of different ΔR for $3n$ and $4n$ emissions, which means different reaction times for different residue products.

Concluding, fitted ΔR for $2n$ emission in DCM suggests that the experimentally missing $1n$ contribution is the largest to CF cross-section, and that the reaction times are likely to be different for different xn emissions.

References

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