Analysis of ^{113}In(α, n)$^{116g/(or)m}$Sb reaction within collective clusterization approach

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Introduction

Antimony-117 has been extensively studied experimentally over the years. The experimental cross-sections for ^{113}In (α, n) ^{116}Sb are available for the decay of the compound nucleus(CN) ^{117}Sb*, to the ground state (g.s.) and metastable state (m.s.) of ^{116}Sb, via 1n-emission using the Activation method where the results are compared with the predictions of the Statistical Hauser-Feshbach Model [1]. The cross sections σ_{1n} are calculated at the various astrophysically important center-of-mass energies (E$_{c.m.}$=9.66-13.64 MeV). This energy range comprises the upper end of the astrophysically relevant energy window that extends from 5.24 MeV to 10.17 MeV.

In the present work, we have applied DCM to study the decay of ^{117}Sb* formed via ^{4}He+^{113}In reaction. The α-induced reaction on ^{113}In-target, within the given center-of-mass energy range (9.66 MeV-13.64 MeV) is found to be a cold-fusion reaction, observed with only 1n-decay (outgoing) channel experimentally observed [1]. Theoretically, "cold fusion" reactions correspond to lowest interaction barriers and largest interaction radii, i.e., of non-compact, elongated nuclear shapes, with excitation energy E$^*_{CN}$ of the compound nucleus formed less than ~20 MeV. After successful application of DCM to analyze the decays of CN to ground as well as metastable states in a "hot-fusion" reaction [2], this is for the first time we apply DCM to study decays of compound nuclei to both ground and metastable states in a "cold fusion" reaction.

Methodology

The quantum mechanical fragmentation theory (QMFT)-based DCM [3], 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.

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TABLE I: DCM calculated channel cross sections $\sigma^{Cal.}_{DCM}$, for the decay of CN ^{117}Sb* to g.s. of ^{116}Sb, Cal.1 and m.s. ^{116m}Sb, Cal. 2 via 1n-emissions, at E^*_{CN}=11.36 MeV, compared with experimental data [1].

Cal.1: g.s. to g.s. decay of ^{117}Sb*				Cal.2: g.s. to m.s. decay of ^{117}Sb*		
Decay-Fragment Mass-No. (A_2)	$\sigma^{Expt.}$ (mb)	ΔR (fm)	$\sigma^{Cal.}_{DCM}$ (mb)	$\sigma^{Expt.}$ (mb)	ΔR (fm)	$\sigma^{Cal.}_{DCM}$ (mb)
E^*_{CN} = 11.360 MeV T=0.974 MeV						
1(1n)	$(55\pm22)\times10^{-3}$	1.15	55×10^{-3}	$(17\pm2.6)\times10^{-3}$	1.04	17×10^{-3}
2-4	-	0.36	6.9×10^{-4}	-	0.32	6.6×10^{-4}
5-20	-	0.19	2.03×10^{-4}	-	0.15	2.01×10^{-4}
54-59	-	-0.06	1.61×10^{-5}	-	-0.062	1.59×10^{-5}

Calculations and Results

Our calculations are made for 'cold-elongated' configurations for quadrupole deformed β_{2i} and "optimum" oriented (θ_i^{opt}) nuclei by optimizing the ΔR value for the best fit of experimental data at each E^*_{CN}. Table.1, Cal. 1 and Cal. 2, presents the calculations for the various channel cross-sections i.e, σ_{ER}, σ_{IMF} and σ_{FF}, respectively, for both g.s. to g.s. and g.s. to m.s. decays of $^{117}Sb^*$ CN at E^*_{CN}= 11.360 MeV. According to our calculations, σ_{FF} is negligible as compared to the σ_{1n} which also suggests that $^{117}Sb^*$ CN is a non-fissioning nuclei.

The combined effect of P_0 and P, i.e., the variation of light mass channel cross sections $\sigma^{Cal.}_{DCM}$ as a function of ℓ in Fig. 1(a) and (b) shows that the ℓ's contributing to $\sigma^{Cal.}_{DCM}$ have the limiting values $\ell_{min} < \ell < \ell_{max}$, and that for the best fitted ΔR's used here, the decay cross sections for unobserved 2n, 3n and ^{4}He decay-channels are negligible while it is maximum for 1n decay channel, the experimentally observed channel. Following the above procedure, at each E^*_{CN}, the DCM calculated 1n channel cross section compare nicely with experimental ones (as shown in Table I) for both kinds of decays. Thus, both g.s. to g.s. and g.s. to m.s. decays of ^{117}Sb* CN are pure CN decays, i.e, the non-compound nucleus (nCN) decay contribution is zero.

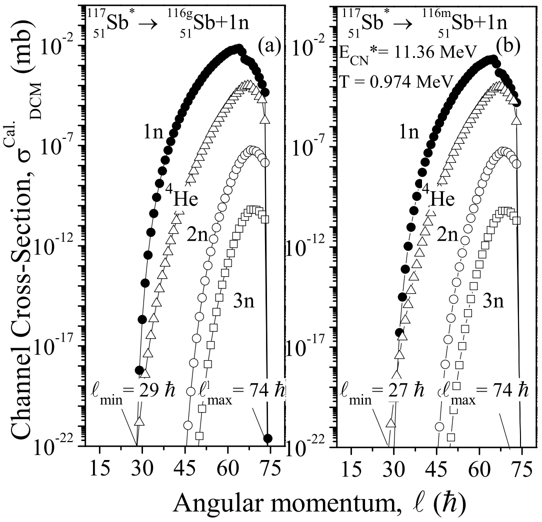

FIG. 1: Decay channel cross sections $\sigma^{Cal.}_{DCM}$, *vs.* angular momentum ℓ for (a) g.s. to g.s. decay, and (b) g.s. to m.s. decays.

References

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