Determination of breakup probability P_{BU} in ^{9}Li+^{208}Pb reaction within the dynamical cluster-decay model.

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Introduction

The compound nucleus (CN) ^{217}At*, formed by projecting neutron-rich ^{9}Li on doubly magic ^{208}Pb, is studied within the dynamical cluster-decay model (DCM) [1] at various center-of-mass energies. Here, in this work, we concentrate on this system at $E_{c.m.}$=28.5 MeV, corresponding to temperature T= 1.145 MeV, where experimental [2] isotopic yields of only heavy mass residues ^{213,214}At, i.e., the light-particles (LPs) evaporation residue (ER) cross sections σ_{xn} for x=3,4 neutrons emission, are measured with fusion-fission (ff) component σ_{ff} taken to be zero.

^{9}Li is a neutron-rich, weakly bound nucleus, and the fusion cross sections for such projectiles are expected to get enhanced due to the extended neutron density profile or the large neutron-skin. Our DCM calculations [1] show that the CN cross section σ_{CN} is negligibly small, compared to the competing non-compound nucleus (nCN) content σ_{nCN}, comprising the processes like that of quasi fission (qf), incomplete fusion (ICF), or deep inelastic collisions (DIC), etc.. Thus, the total fusion cross section $\sigma_{fusion} = \sigma_{CN} + \sigma_{nCN}$. Alternatively, in the following we look for the projectile breakup effects, in competition to its fusion.

Methodology

A. Dynamical cluster-decay model

The Dynamical cluster-decay model (DCM) of Gupta and Collaborators [3, 4] is the non-statistical description of the dynamical mass motion of preformed clusters through the interaction barriers which treat all types of CN decays, i.e., ER's or LPs ($A_2 \leq 4$), IMFs ($5\leq A_2 \leq 20$) and ff fragments on the same level (IMFs are a part of ff), in contrast to statistical models where each type of decay (ER or ff) is treated on different footings. The decay of a hot and rotating CN in the DCM is worked out in terms of the decoupled relative separation R and mass (and charge) asymmetries η=(A$_1$-A$_2$)/(A$_1$+A$_2$) (and η_Z=(Z$_1$-Z$_2$)/(Z$_1$+Z$_2$)) coordinates, defining the CN decay cross section for ℓ partial waves as

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

Here, P_0 is the preformation probability, referring to η-motion and P, the penetrability, to R-motion. μ is the reduced mass with m as the nucleon mass. ℓ_{max} is the maximum angular momentum, defined for $\sigma_{ER}\to 0$. Eq. (1) gives $\sigma_{ER} = \sum_{A_2=1}^{4}\sigma_{(A_1,A_2)} = \sum_{x=1}^{4}\sigma_{xn}$, $\sigma_{ff} = 2\sum_{A_2=5}^{A/2}\sigma_{(A_1,A_2)}$, and their sum σ_{CN} ($=\sigma_{ER}+\sigma_{ff}$). Also, Eq. (1) gives σ_{nCN}, calculated as the quasi-fission (qf)-like decay where P_0=1, i.e, for σ_{nCN} we use DCM(P_0=1) and in case the σ_{nCN} were not measured, it can be estimated empirically, as $\sigma_{nCN} = \sigma_{fusion}^{Expt.} - \sigma_{CN}^{Cal.}$.

Having defined the relevant σ's in the DCM, we can write the statistical CN fusion/ formation probability P_{CN} [3], and the CN survival probability P_{surv} [4] against fission, i.e., the probability of fused system to de-excite by emission of neutrons or LPs, equivalently, the ER, rather than fission, each given by

$$P_{CN} = \frac{\sigma_{CN}}{\sigma_{fusion}} = 1 - \frac{\sigma_{nCN}}{\sigma_{fusion}}, \qquad (2)$$

$$P_{surv} = \frac{\sigma_{ER}}{\sigma_{CN}} = 1 - \frac{\sigma_{ff}}{\sigma_{CN}}, \qquad (3)$$

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P_{CN} takes care of the nCN effects, and P_{surv} of the ff process. In other words, P_{CN}=1 if σ_{nCN}=0, and P_{surv}=1 if σ_{ff}=0.

B. Estimation of breakup probability

The statistical relations above allow us to write for CN process, the ER cross section as [5, 6]:

$$\sigma_{ER}^{CN} = \sum_{\ell=0}^{\ell_{max}} \sigma_{fusion} P_{CN} P_{surv}. \qquad (4)$$

For fusion studies involving weakly bound nuclei, if breakup (BU) occurs in competition with fusion, we can define the breakup Probability P_{BU} as:

$$P_{BU} = 1 - P_{CN} \qquad (5)$$

Thus, P_{BU} is the probability that the projectile BU rather than fuse. Then, from Eq. (4), the ER cross-section for breakup is

$$\sigma_{ER}^{BU} = \sum_{\ell=0}^{\ell_{max}} \sigma_{fusion} P_{BU} P_{surv}. \qquad (6)$$

so that the total ER cross section (σ_{ER}^{total}) is the sum of σ_{ER}^{CN} and σ_{ER}^{BU}. Note, however, that if σ_{nCN} were a measured quantity, like the qf process, then for BU to ocuur,

$$P_{BU} = 1 - (P_{CN} + P_{nCN}) \qquad (7)$$

In the present reaction under study, however, σ_{nCN} is determined empirically, and hence Eq. (5) is valid.

Calculations and Results

Table I gives the ER cross sections for the CN and BU processes, calculated by using Eqs. 4 and 6, respectively, with their sum giving σ_{ER}^{total} (=$\sigma_{ER}^{CN}+\sigma_{ER}^{BU}$) which is comparable with the experimental data. In Fig.1, we have shown the variation of P_{CN}, P_{BU} and σ_{fusion} (=$\sigma_{CN}+\sigma_{nCN}$) as a function of angular momentum for 3n and 4n decay channels. Fig. 1 shows the expected behavior of P_{CN} and P_{BU} as complimentary processes. Evidently, the main contribution to σ_{ER}^{total} is from σ_{ER}^{BU}, i.e., σ_{ER}^{BU} ($\equiv\sigma_{nCN}$) contribution to the total fusion cross section is large.

TABLE I: The DCM calculated ER cross sections for CN and BU processes, compared with the experimental value. Note, P_{surv}=1 since σ_{ff}=0.

Decay Channel	σ_{ER}^{CN} (mb)	σ_{ER}^{BU} (mb)	σ_{ER}^{total} (mb)	$\sigma_{ER}^{Expt.}$ (mb)
^{217}At* $\rightarrow$ ^{214}At+3n	0.09	8.31	8.4	8.4±1.9
^{217}At* $\rightarrow$ ^{213}At+4n	0.74	68.6	69.34	69.3±8.

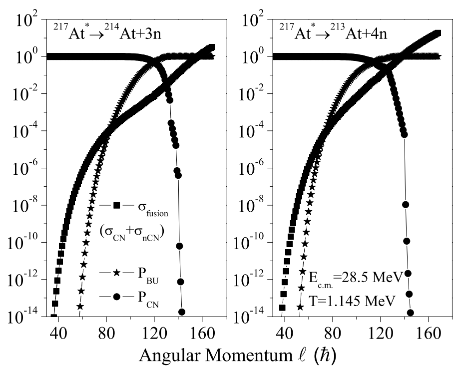

FIG. 1: The DCM calculated P_{CN}, P_{BU} and σ_{fusion} (= σ_{CN} + σ_{nCN}) for 3n and 4n decay channels as a function of angular momentum.

References

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