Decay of ^{217}At* formed in the ^{9}Li+^{208}Pb reaction using the dynamical cluster-decay model

Arshdeep Kaur,* Bivash R. Behera, and Raj K. Gupta
Department of Physics, Panjab University, Chandigarh - 160014, INDIA

Introduction

In the fusion process, a compound nucleus (CN) is formed, where the projectile fuses with the target nucleus, whose formation or decay cross-section σ_{CN} is the sum of evaporation residue (ER) cross section σ_{ER} and the fusion-fission cross section σ_{ff}, i.e., $\sigma_{CN} = \sigma_{ER} + \sigma_{ff}$. Then, there are other processes of quasi-fission (qf), incomplete fusion or deep-inelastic collisions, etc., where the CN is not formed but, like in qf, a few nucleon transfer between target and projectile occurs, referred to as the non-compound nucleus (nCN) process with cross-section σ_{nCN}, such that the (total) fusion cross section $\sigma_{fus} = \sigma_{CN} + \sigma_{nCN}$.

Nuclear reactions involving weakly or loosely bound projectiles are of great interest now a days. The low breakup threshold of these nuclei are posing new challenges in both theory and experiments. An important aspect of collisions of loosely bound nuclei is that fusion is influenced atleast by two factors, due to: (i) lower binding energy of weakly bound nuclei, barriers are lower which enhances fusion cross section at subbarrier energies; (ii) the coupling of the elastic channel with breakup, inelastic and transfer channels. However, in a recent work of Gupta and Collaborators [1], it is shown that, within the dynamical cluster-decay model (DCM), σ_{fus} can be obtained quite accurately as a pure CN process at a fixed value of the neck-length ΔR (the only parameter) for various reactions formed with a loosely bound projectile on different targets at the same beam energy.

In this paper, we extend the above work further to loosely bound ^{9}Li projectile on stable ^{208}Pb target, forming ^{217}At*. Similar to [1], we are able to fit the total cross section σ_{fus} at one value of ΔR, but, in addition, we find that, instead of CN, the nCN is contributing most towards the total fusion cross section.

Dynamical cluster-decay model

The Dynamical cluster-decay model (DCM) of Gupta and Collaborators [1, 2] is used to study the heavy ion reactions at low energies. The DCM is the non-statistical description of the dynamical mass motion of preformed clusters through the interaction barriers which treat all types of emission, i.e., ERs ($A_2 \leq 4$), IMFs ($5 \leq A_2 \leq 20$) and ff fragments on the same level in contrast to statistical models where each type of emission (ERs, IMFs or ff) is treated on different footing (IMFs are a part of ff). The decay of hot and rotating CN in the DCM is worked out in terms of the decoupled relative separation R and mass (and charge) asymmetries $\eta = (A_1 - A_2)/(A_1 + A_2)$ (and $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$) coordinates, defining the CN decay cross-section as

$$\sigma_{A_1,A_2} = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell_{max}} (2\ell+1) P_0 P; \quad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{1}$$

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 light-particle evaporation residue cross section $\sigma_{ER} \rightarrow 0$.

The above formula is also applied to nCN decay channel (treated as qf process) for which P_0=1 since the incoming channel (target and projectile nuclei) can be considered to have not yet lost their identity for the qf process.

*Electronic address: arshdeep.pu@gmail.com

TABLE I: The DCM calculated (total) fusion cross section σ_{fus} at a fixed neck-length ΔR (Cal.1); and each decay channel fitted as CN and nCN contributions with different ΔR's (Cal.2).

Cal.1 (Fixed ΔR)			Cal.2 (Fitted ΔR to each channel cross section)					
			CN contribution		nCN contribution			
Decay-channel	$\sigma_{fus}^{Cal.1}$ (mb)	σ_{fus}^{Expt} (mb)	ΔR (fm)	$\sigma_{CN}^{Cal.2}$ (mb)	σ_{nCN}^{emp} (mb)	ΔR (fm)	$\sigma_{nCN}^{Cal.2}$ (mb)	$\sigma_{fus}^{Cal.2}$ (mb)
$E_{c.m.}$=38.1 MeV ($E_{lab.}$=39.88 MeV)								
ΔR = 1.8121 fm								
1n	722	-	1.0	3.08×10^{-3}	0	0.1	1.41×10^{-7}	3.08×10^{-3}
2n	29.6	-	1.0	1.31×10^{-4}	0	0.1	1.83×10^{-8}	1.31×10^{-4}
3n	0.643	-	0.3	5.09×10^{-11}	0	0.1	3.63×10^{-9}	3.63×10^{-9}
4n	8.6×10^{-3}	218±22	2.0	1.05	216.95	1.4475	217	218.05
5n	5.34×10^{-5}	534±29	2.0	3.6×10^{-4}	534	1.5369	534	534
6n	6.19×10^{-7}	-	2.0	1.91×10^{-6}	0	0.1	8.75×10^{-11}	1.91×10^{-6}
$\sum_{x=1}^{6} xn$	752.243	752±37		1.05	750.95		751	752.05

Calculations and Results

Using the DCM, we have studied the decay of ^{217}At* formed in ^{9}Li+^{208}Pb reaction. Table I gives the DCM calculated fusion cross section for ^{217}At* at the near barrier energy $E_{c.m.}$=38.1 MeV (Coulomb barrier for this reaction is 38.48 MeV), compared with the experimental data [3]. First of all, we fit the total fusion cross section σ_{fus} at a fixed ΔR value, without caring for the values obtained for individual channels. Interestingly, we are able to fit the total σ_{fus}^{Expt} nealy exactly, as the pure CN decay process (compare with $\sigma_{fus}^{Cal.1}$). However, if we compare the measured 4n and 5n decay channels, the pure CN fits are very poor and calls for the empirical nCN contributions. Note that the calculated 1n contribution is very large which could possibly be reduced to (nearly) zero, if data for other (IMF and/or ff) decay channels were available [4].

We have also fitted the CN cross section $\sigma_{CN}^{Cal.2}$ as a pure CN process in terms of different ΔR's for the best fit to observed individual decay channels (4n and 5n), reducing the contributions of other possible channels (1-3n, and 6n) to nearly zero. Then, in turn the empirically obtained σ_{nCN}^{emp} were fited as the qf process (P_0=1). We find that the fits are nearly exact (compare $\sigma_{fus}^{Cal.2} = \sigma_{CN}^{Cal.2} + \sigma_{nCN}^{Cal.2}$ with σ_{fus}^{Expt}), and the $\sigma_{nCN}^{Cal.2}$ constittute most of the fusion cross section. The same results are obtained for other, below and above barrier, energies. Further calculations are underway.

Acknowledgements

Part of computation was done on the Department's CAS-FIST-PURSE HPCC facility.

References

[1] M. Kaur, B. Singh, M. K. Sharma, and R. K. Gupta, Phys. Rev. C **92**, 024623 (2015).

[2] R. K. Gupta, Lecture Notes in Physics 818 *Clusters in Nuclei*, ed C. Beck, Vol.I, (Springer Verlag), p. 223 (2010); and earlier references there in it.

[3] A. M. Vinodkumar *et al.*, Phys. Rev. C **80**, 054609 (2009).

[4] S. Chopra, M. Bansal, M. K. Sharma, and R. K. Gupta, Phys. Rev. C **88**, 014615 (2013).