Competition among different decay modes of compound nuclei with A=60

Mandeep Kaur[1],* BirBikram Singh[1],† Manoj K. Sharma[2], and Raj K. Gupta[3]
[1]*Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib-140406, India.*
[2]*SPMS, Thapar University, Patiala-147004, India. and*
[3]*Department of Physics, Panjab University, Chandigarh-160014, India.*

Introduction

Within the dynamical cluster decay model (DCM), it has been found that the value of empirically fitted ΔR^{emp} can be fixed uniquely for a particular set of reactions induced by the same projectile (loosely bound or stable) at the same incident energy [1]. For a given projectile at a fixed E_{lab} on different targets, we are able to address the total fusion cross section (σ_{fus}) for all the reactions under study. Following this work, the decay mechanism of $^{60}Zn^{*}$,$^{60}Ni^{*}$ and $^{60}Fe^{*}$ compound nuclei (CN) formed in the reactions ^{4}He+^{56}Ni, ^{4}He+^{56}Fe and ^{4}He+^{56}Cr respectively, have been investigated using DCM, which have not been explored experimentally [2]. To fix ΔR_{emp} for that study, we have chosen reactions ^{4}He+^{64}Zn, ^{4}He+^{44}Ca and ^{4}He+^{40}Ca at E_{lab}∼10 MeV for which the experimental data is available. The values of ΔR_{emp} were then used further to predict the σ_{fus} of the CN, under investigation. Neutron to proton (N/Z) ratio for the CN $^{60}Zn^{*}$,$^{60}Ni^{*}$ and $^{60}Fe^{*}$ is 1, 1.1 and 1.3 respectively. The effect of changing N/Z ratio has been analysed on the total fusion cross section (σ_{fus}).

Generally the fusion cross section (σ_{fus}) is calculated by summing up the cross sections of various decays such as light particles (LPs), Intermediate mass fragments(IMFs), heavy mass fragments (HMFs). For light compound systems with A_{CN} ∼ 40 - 80, the LPs (with Z ≤2) emission is always accompanied by the IMFs (with 2 ≤ Z ≤10 and 5≤A≤20) and symmetric fragments (SFs) having range $A/2 \pm 10$. The major advantage of DCM is that all the decay processes LPs, IMFs and SFs are treated on equal foothold which is not the case with the competing statistical models. It is to be noted here that the contribution of LPs and IMFs is more prominent as compared to SFs in this mass region [3]. In the present work, it is highly motivating to explore the competition among different modes of decay i.e., LPs, IMFs and SFs from CN having same mass number A but different N/Z ratio i.e. $^{60}Zn^{*}$,$^{60}Ni^{*}$ and $^{60}Fe^{*}$. The effect of the angular momentum for different decay modes is also studied.

Methodology

The DCM [1–3], worked out in terms of collective co-ordinates of mass (and charge) asymmetries, for ℓ-partial waves, gives the compound nucleus (CN) decay cross-section as

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

where, $\mu = [A_1A_2/(A_1+A_2)]m$ is the reduced mass, with m as the nucleon mass and ℓ_{max} is the maximum angular momentum. P is penetrability of interaction barrier (of the preformed clusters with preformation probability P_0), calculated as the WKB tunneling probability, around the Coulomb barrier. Then, the σ_{fus} is given by

$$\sigma_{fus} = \sigma_{LPs} + \sigma_{IMFs} + \sigma_{SFs}. \tag{2}$$

Calculations and Discussions

Fig.1 presents the variation of summed up preformation probability ($\sum P_0$) with angular momentum for the different decay modes of CN ^{60}Zn*,^{60}Ni* and ^{60}Fe*. for all the three

*Electronic address: randhawamandeep97@gmail.com
†Electronic address: birbikramsingh@sggswu.edu.in

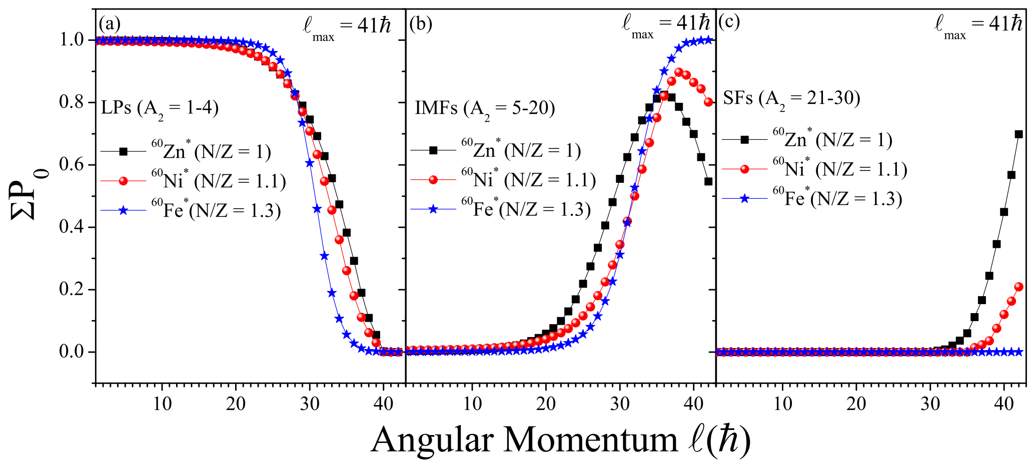

FIG. 1: The $\sum P_0$ for the (a) LPs (b) IMFs and (c) SFs in the decay of $^{60}Zn^*$, $^{60}Ni^*$ and $^{60}Fe^*$ CN formed in ^{4}He induced reactions at $E_{lab} \sim 10$ MeV.

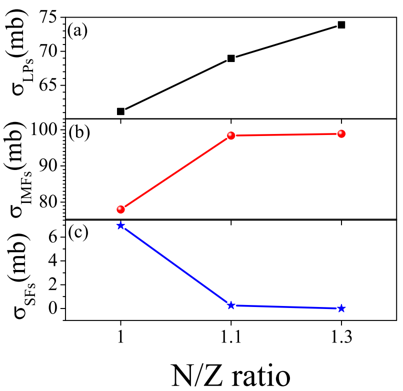

FIG. 2: The DCM calculated cross-sections (a) σ_{LPs}, (b)σ_{IMFs} and (c) σ_{SFs} in the decay of CN $^{60}Zn^*$, $^{60}Ni^*$ and $^{60}Fe^*$ and their variation with N/Z ratio.

compound systems, $\sum P_0$ remains constant ($\sim$ 1) till around $\ell{\sim}25\hbar$, then decreases ($\sim$ 1 to 0) with increase in the value of angular momentum $\ell(\hbar)$ for LPs . The $\sum P_0$ shows almost similar trend for the LPs for all the CN under study. But the $\sum P_0$ for IMFs increases (from 0) with increase in the value of ℓ. The P_0 starts increasing around $\ell{\sim}20\hbar$, higher for IMFs as N/Z increases. We also observe that the value of $\sum P_0$ increases with increase in the value of N/Z ratio. Also, the contribution of $\sum P_0$ for SFs in the ^{60}Zn* and ^{60}Ni* increases at higher values, but it is almost zero at all ℓ-values for ^{60}Fe*. The $\sum P_0$ for the SFs of ^{60}Zn* is more as compared to ^{60}Fe* and ^{60}Ni* as shown in Fig. 1(c). These values of $\sum P_0$ for LPs, IMFs and SFs contribute towards the σ_{fus} depending upon their respective penetrability values.

The variation of different decay cross section such as light particle cross section (σ_{LPs}), intermediate mass fragments cross section (σ_{IMFs}) and symmetric fragment cross section (σ_{SFs}) with increasing N/Z ratio is shown in Fig.2 (a) and 2(b) and 2(c), respectively. The contribution of both σ_{LPs} as well σ_{IMFs} increases with increase in the value of N/Z , but σ_{SFs} decreases with increase in N/Z ratio. Also, we observe that the contributions of σ_{LPs} and σ_{IMFs} is more prominent as compared to σ_{SFs}.

References

[1] M. Kaur et al., PRC **92**, 024623 (2015); IJPAP **13**, 154 (2017); Proc. of DAE symp. on Nucl. Phys. **60**, 590 (2015); **60**, 594 (2015).

[2] B.B. Singh et al., Proc. of DAE symp. on Nucl. Phys. **60**, 598 (2015).

[3] R.K. Gupta, *et al.*, PRC **71**, 014601 (2005); IJMPE **15**, 699 (2006); PRC **77**, 054613 (2008); JPG:NPP **36**, 085105 (2009); PRC **80**, 034618 (2009); PRC **90**, 024619 (2014).