Decay of A = 60 compound nuclei investigated using dynamical cluster-decay model

Mandeep Kaur[1,*], Sarbjeet 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 Institute of Engineering and Technology, Patiala-147004, INDIA
[3]Department of Physics, Panjab University, Chandigarh-160014, INDIA
email: *randhawamandeep97@gmail.com, $birbikram.singh@gmail.com

Introduction

Fission reactions that produce fragments close to one half the mass of the composite system are usually observed in heavy nuclei. In light mass systems, symmetric splitting is rarely observed and poorly understood. In contrast to heavy mass compound-nucleus fission, where the symmetric breakup is favored, the dependence of the macroscopic potential-energy surface on nuclear deformation and shape asymmetry favors the breakup of lighter mass systems into two unequal-mass fragments. But in some of the recent studies, it has been shown that compound-nucleus fission can also play a significant role in heavy-ion reactions forming light mass composite systems with A_{CN} ~ 45-60 [1-2].

Recently, within the quantum mechanical fragmentation theory (QMFT)-based dynamical cluster decay model (DCM) [3-5], it has been found that the value of empirically fitted neck length parameter 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 [5]. To fix ΔR_{emp}, we had chosen the reactions ^{4}He+^{64}Zn, ^{4}He+^{44}Ca, and ^{4}He+^{40}Ca at $E_{c.m.}$~10-17 MeV for which the experimental data is available. The values of ΔR_{emp} were then used to predict the σ_{fus} 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, which have so-far not been explored experimentally. In our earlier studies, we found that the decay of these CN have main contributions from light particles/ evaporation residues followed by small contributions from intermediate mass fragments [5]. In this work, we have presented the effect of neutron to proton (N/Z) ratio on the decay of CN, specifically, through symmetric mass fragments (SMFs). The effect of the angular momentum for SMFs decay mode is also studied.

Methodology

The QMFT-based DCM [3-5] provides an alternate to statistical models, and treats the light particles (LPs), Intermediate mass fragments (IMFs) and symmetric mass fragments (SMFs) emissions from CN, on equal footings. The missing nuclear structure information of compound nucleus in statistical models, enters in the DCM via preformation probability P_0 of the fragments. For ℓ-partial waves, the compound nucleus decay cross-sections read as

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

where, $\mu = [A_1A_2/(A_1 + A_2)]$ m, is the reduced mass, with m as the nucleon mass and ℓ_{max}, the maximum angular momentum. The ℓ_{max} is fixed for the vanishing of light particles cross-section σ_{LPs}. In Eq. (1), P_0 is obtained by solving the stationary Schrödinger equation, refers to η-motion and the penetrability, P calculated as the WKB tunneling probability, in reference to R-motion.

Calculations and Discussions

The variation of summed up preformation probability ($\sum P_0$) and summed up penetration probability ($\sum P$) over angular momentum $\ell_{max}(\hbar)$ for the decay of ^{60}Zn*, ^{60}Ni* and ^{60}Fe* is shown in Fig. 1(a) and 1(b), respectively. The $\sum P_0$ increases as N/Z ratio increases, i.e., maximum for SMFs in the decay ^{60}Zn* having N/Z = 1, i.e. SMFs are more favored in case of N=Z, which means that symmetric breakup is favored in case ^{60}Zn*. In addition to preformation probability, $\sum P$ is also a significant contributor towards

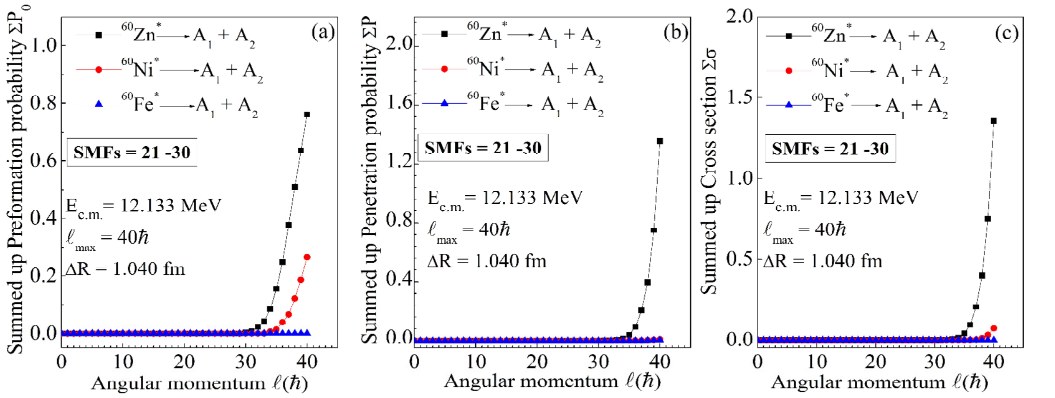

Fig. 1 Variation of (a) summed up preformation factor $\sum P_0$ (b) summed up penetration probability $\sum P$ (c) summed up cross section $\sum\sigma$ with angular momentum $\ell(\hbar)$ for the symmetric decay of $^{60}Zn^*$, $^{60}Ni^*$ and $^{60}Fe^*$.

the DCM based cross sections (see eq. 1). Fig. 1(b) shows that penetration probability is negligible for SMFs fragments at all ℓ-values for the decay of $^{60}Ni^*$ and $^{60}Fe^*$ having N/Z = 1.1 and N/Z = 1.3, respectively, but $\sum P$ for the SMFs increases with increase in angular momentum for the decay of $^{60}Zn^*$, i.e., N /Z = 1.

This variation of preformation probability and penetration probability in turn influences the summed up SMFs cross-sections $\sum\sigma$. The $\sum\sigma$ is shown in Fig. 1 (c) for $^{60}Zn^*$, $^{60}Ni^*$ and $^{60}Fe^*$. The contribution of the $\sum\sigma$ (mb) for SMFs (A = 20-30) is negligible at all ℓ-values, both for $^{60}Ni^*$ and $^{60}Fe^*$. However, there is an increase in σ_{SMFs} at higher ℓ-values in case of $^{60}Zn^*$.

We have also explored the contributions of SMFs (A=21-30, hollow squares), as shown in Fig. 2, and it is observed that that there is a significant contri-bution of SMFs like ^{30}P+^{30}P (filled squares) in decay of $^{60}Zn^*$, Fig. 2 (a), but the contribution of ^{30}Si+^{30}Si in the decay of $^{60}Ni^*$ and ^{30}Al+^{30}Al in the decay of $^{60}Fe^*$ is quite small, evident from Fig. 2 (b and c), in the total σ_{SMFs}. Also, we observe that the contribution of SMFs rise with increase in temperature of CN, except for $^{60}Fe^*$. The study on few more such systems in this mass region is in progress, and we intend to present comprehensive analysis during the symposium.

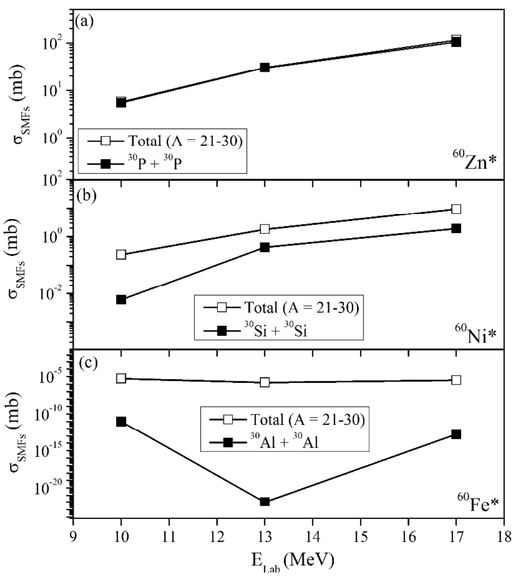

Fig. 2 The variation of σ_{SMFs} with incident energy for the symmetric decay channel of (a) $^{60}Zn^*$ (b) $^{60}Ni^*$ and (c) $^{60}Fe^*$.

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