Entrance channel effects of Z=107 superheavy isotopes synthesized using hot fusion reactions

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Introduction

The theoretically predicted "island of stability" in superheavy mass region has motivated the synthesis of these nuclei via heavy-ion fusion reactions. The mass-asymmetric reactions of actinide nuclei with lighter projectiles (Mg to K) leads to the synthesis of superheavy nuclei (SHN) upto Z=106. However, due to enhancement in excitation energy and consequent depletion of shell effects, cold fusion reactions (^{208}Pb or ^{209}Bi targets) were preferred for the production of Z=107-112 [1]. Higher SHN (Z=113-118) were synthesized via hot fusion reactions using ^{48}Ca-projectile due to smaller production cross-sections obtained in cold fusion processes [2]. The short life-time and low production cross-section have posed difficulties in studying the various properties of SHN. Therefore, the quest of suitable target-projectile combinations for the synthesis of stable SHN is still going on.

Since Z=107-112 were synthesized in cold fusion reactions which result in neutron deficient isotopes, so the coalescence of neutron rich isotopes through hot fusion reactions still attract much attention. An additional reason could be that, the actinide nuclei are prolate deformed and equatorial collision with such nuclei can result in a compact configuration and the system may have larger fusion probability than in reactions involving spherical target nuclei, such as Pb or Bi. In the present study, we have estimated the capture and fusion-fission cross-sections of Z=107 superheavy nucleus formed via different hot fusion reactions at energies near and above the Coulomb barrier. The cross-sections are predicted by using ℓ-summed Wong model [3] and the capture and fusion-fission dynamics is explored in terms of mass-asymmetry and compound nucleus formation probability (P_{CN}).

Methodology

According to ℓ-summed Wong model [3], the fusion cross-sections in terms of angular momentum partial waves for deformed and oriented nuclei are given by expression

$$\sigma_{fusion}(E_{c.m.},\theta_i) = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_\ell P_{CN} \quad (1)$$

The fusion for superheavy nuclei constitute only a part to the capture events, so the fusion cross-sections (σ_{fusion}) are always less than the capture cross-sections ($\sigma_{Cap.}$). Also the contribution of evaporation residue cross-sections (σ_{ER}) to σ_{fusion} is very small as compare to fusion-fission events (σ_{ff}), hence in case of SHN $\sigma_{fusion} \approx \sigma_{ff}$. In Eq. (1), the P_ℓ is the barrier penetration probability calculated using Hill-Wheeler approach [4] and P_{CN} is the compound nucleus formation probability calculated as [5]

$$P_{CN}(E^*) = \frac{P^0_{CN}}{1+exp[(E^*_B - E^*_{CN})/4]} \quad (2)$$

Calculations and Results

The ℓ-summed Wong model is applied to estimate the capture and fusion-fission cross-sections of ^{258,267,269,271}Bh* isotopes formed in ^{48}Ti+^{210}At→^{258}Bh* (η=0.63), ^{48}Ca+^{223}Fr→^{271}Bh*(η=0.65), ^{36}S+^{231}Pa→^{267}Bh*(η=0.73), ^{31}P+^{238}U→^{269}Bh* (η=0.77), ^{30}Si+^{237}Np→^{267}Bh*(η=0.77), and ^{24}Mg+^{243}Am→^{267}Bh*(η=0.82) reactions. Fig.1, shows the theoretically calculated

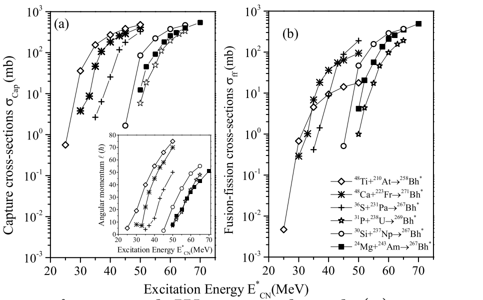

FIG. 1: ℓ-summed Wong predicted (a) capture (σ_{Cap}) and (b) fusion-fission (σ_{ff}) cross-sections for Z=107 formed in different hot fusion reactions.

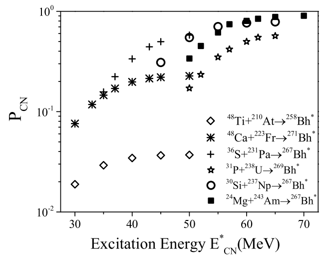

FIG. 2: Compound nucleus formation probability (P_{CN}) plotted as a function of excitation energy (E^*_{CN}) for Z=107 superheavy nucleus.

capture (σ_{Cap}) and fusion-fission (σ_{ff}) cross-sections as a function of excitation energy (E^*_{CN}). The cross-sections increase smoothly and start saturating at higher values of energies. For the chosen reactions, the magnitude of σ_{Cap} is nearly same however a significant variation is observed in σ_{ff}. This variation of σ_{ff} from σ_{Cap} is low for the reactions with larger mass-asymmetric reactions and vice-versa, indicating different contribution of quasi-fission for them. Fusion-fission cross-sections are observed higher for ^{24}Mg- and ^{30}Si-induced reactions followed by ^{36}S projectile. The excitation energies of former two reactions is quite high which diminish the shell-effects, hence ^{36}S-induced reaction seems a better choice (having larger cross-sections at relatively lower excitation energies). Additionally, the doubly magic ^{48}Ca-projectile, used to produce neutron rich isotopes, also results in comparable σ_{ff} at lower excitation energies which are close to ^{36}S-induced reaction. This variation in cross-sections is due to the compound nucleus formation probability (P_{CN}) values which depends on entrance channel effects.

The P_{CN} show dependance on fissility parameter (x_m) which is connected with repulsive and attractive forces in reaction entrance channel. With increase in the value of x_m, P_{CN} and hence cross-section decreases. The variation of P_{CN} with energy is shown in Fig.2. The highest P_{CN} values are obtained for ^{24}Mg and ^{30}Si followed by ^{36}S-induced reaction. The P_{CN} value for ^{48}Ca projectile is close to ^{36}S. The least P_{CN} is obtained with ^{48}Ti. These results are in order with the one obtained from Fig.1. The detailed study of these reactions is carried out in our recent work which is submitted to communication in theoretical physics journal.

Although the higher fusion-fission cross-sections and compound nucleus formation probabilities are observed for ^{24}Mg- and ^{30}Si-induced reactions, but ^{36}S-induced reaction may be preferred for the synthesis of Z=107 due to relatively lower excitation energies. Alternatively, the ^{48}Ca projectile can be used to synthesize the neutron rich isotope.

Acknowledgments

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