Synthesis of superheavy element Z=121

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Introduction

Superheavy elements (SHEs) up to Z=118 have been prepared in the laboratory till now and endeavor to produce Z=119 and Z=120 is going on. The fusion reactions include the complete fusion followed by fission or evaporation residue as well as quasi-fission processes where there are mass transfers which occur in a short time scale. The relative contributions of these processes are estimated from the different variables such as entrance channel asymmetry, excitation energy, fission and quasi-fission barrier etc.

In the present work our aim is to predict the evaporation residue cross section for the synthesis of SHE, Z=121 using the reaction ^{48}Ca+^{258}Md→^{306}121, ^{50}Ti+^{254}Es→^{304}121, ^{50}Ti+^{252}Es→^{302}121 and ^{54}Cr+^{249}Bk→^{303}121.

Theory

The potential

The interaction barrier for two colliding nuclei is given as

$$V = \frac{Z_1 Z_2 e^2}{r} + V_P(z) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2} \qquad (1)$$

$V_P(z)$ is the proximity potential given as

$$V_P(z) = 4\pi\gamma b \frac{C_1 C_2}{C_1 + C_2} \phi\left(\frac{z}{b}\right) \qquad (2)$$

with $\gamma = 0.9517[1 - 1.7826(N-Z)^2/A^2]$ is the nuclear surface tension coefficient, z is the distance between the near surfaces of the projectile and target, ℓ is the angular momentum, μ is the reduced mass.

The cross section

The cross section of SHE production in a heavy ion fusion reaction with subsequent emission of x neutrons is given by

$$\sigma_{ER}^{xn} = \frac{\pi}{k^2} \sum_{\ell=0}^{\infty} (2\ell+1) T(E,\ell) P_{CN}(E,\ell) W_{sur}^{xn}(E^*,\ell) \qquad (3)$$

Wong [2] obtained the following analytic expression for the capture cross section,

$$\sigma_{capture} = \frac{R_0^2 \hbar\omega_0}{2E} \ln\left\{1 + \exp\left[\frac{2\pi(E - E_0)}{\hbar\omega_0}\right]\right\} \qquad (4)$$

This formula depends on Coulomb barrier position R_0, barrier height E_0, and $\hbar\omega_0$.

Probability of compound nucleus formation P_{CN} is calculated using the equation

$$P_{CN}(E) = \frac{\exp\{-c(x_{eff} - x_{thr})\}}{1 + \exp\left\{\frac{E_B^* - E^*}{\Delta}\right\}} \qquad (5)$$

where E^* is the excitation energy of the compound nucleus (CN), E_B^* denotes the excitation energy of the compound nucleus when the center-of-mass beam energy is equal to the Coulomb and proximity barrier and Δ is an adjustable parameter

x_{eff} is the effective fissility defined as:

$$x_{eff} = \left[\frac{(Z^2/A)}{(Z^2/A)_{crit}}\right]\left(1 - \alpha + \alpha f(K)\right), \qquad (6)$$

with $(Z^2/A)_{crit}$, $f(K)$ and K is given by:

$$(Z^2/A)_{crit} = 50.883\left[1 - 1.7286\left(\frac{(N-Z)}{A}\right)^2\right], \qquad (7)$$

$$f(K) = \frac{4}{K^2 + K + \frac{1}{K} + \frac{1}{K^2}} \qquad (8)$$

$$K = (A_1/A_2)^{1/3}. \qquad (9)$$

where Z, N and A represent the atomic number, neutron number and mass number respectively. A_1 and A_2 are mass number of projectile and target respectively. x_{thr}, and c are the adjustable parameters.

The survival probability under the evaporation of x neutrons is,

$$W_{sur} = P_{xn}(E^*) \prod_{i=1}^{i_{\max}=x} \left(\frac{\Gamma_n}{\Gamma_n + \Gamma_f}\right)_{i,E^*} \qquad (10)$$

where the index ‘i’ is equal to the number of emitted neutrons, P_{xn} is the probability of emitting exactly xn neutrons, E^* is the excitation energy of the compound nucleus, Γ_n and Γ_n represent the decay width of neutron evaporation and fission respectively.

Vandenbosch and Huizenga have suggested a classical formalism to calculate Γ_n/Γ_f as:

$$\frac{\Gamma_n}{\Gamma_f} = \frac{4A^{2/3}a_f(E^*-B_n)}{K_0 a_n[2a_f^{1/2}(E^*-B_f)^{1/2}-1]} \times \exp[2a_n^{1/2}(E^*-B_n)^{1/2}-2a_f^{1/2}(E^*-B_f)^{1/2}] \qquad (11)$$

where A is the mass number of the nucleus considered, B_n is the neutron separation energy. The constant K_0=10MeV. The parameters $a_n = A/10$ and $a_f = 1.1a_n$ are the level density parameters of the daughter nucleus and the fissioning nucleus at the ground state and saddle configurations respectively and B_f is the fission barrier.

Results and Discussion

Interaction barrier for the fusion reactions ^{48}Ca+^{258}Md→^{306}121, ^{50}Ti+^{254}Es→^{304}121, ^{50}Ti+^{252}Es→^{302}121 and ^{54}Cr+^{249}Bk→^{303}121 is studied using the Coulomb and proximity potential.

The probability of compound nucleus formation as a function of center of mass energy is studied. The capture cross section is calculated using the well known Wong formula [1]. The fusion cross section is calculated by using the value of P_{CN}. Also the ER excitation functions in 2n, 3n, 4n and 5n channel are calculated. The corresponding plots for ER excitation functions are shown in Fig. 1. In Table 1, we listed the maximum ER excitation function for the above mentioned reaction leading to isotopes of SHE, Z=121 for 2n. 3n, 4n and 5n evaporation channel. Using the same theory, we have already studied the ER excitation functions for the SHE with Z=114,116-120, 122 and 124 and predicted the most probable reactions to synthesize these SHEs [2]. These works proves the effectiveness of our calculation.

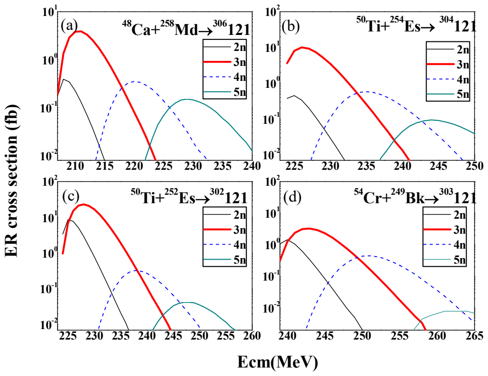

Figure 1. The predicted ER excitation functions for different reactions leading to different isotopes of superheavy element with Z=121.

Reaction	ER cross section in fb			
	2n	3n	4n	5n
^{48}Ca+^{258}Md→^{306}121	0.39	3.89	0.35	0.046
^{50}Ti+^{254}Es→^{304}121	0.45	10.0	0.58	0.017
^{50}Ti+^{252}Es→^{302}121	8.62	23.1	0.33	0.002
^{54}Cr+^{249}Bk→^{303}121	1.45	3.28	0.45	0.006

Table 1. Maximum ER cross section for the superheavy element, Z=121.

The calculated maximum value of 2n, 3n, 4n, 5n channel cross section are 8.62 fb for the reaction ^{50}Ti+^{252}Es→^{302}121, 23.1 fb for the reaction ^{50}Ti+^{252}Es→^{302}121, 0.58 fb for the reaction ^{50}Ti+^{254}Es→^{304}121fb, 0.046fb for the reaction ^{48}Ca+^{258}Md→^{306}121 respectively.

References

[1] C. Y. Wong, Phys. Rev. Lett. **31**, 766 (1973).

[2] K. P Santhosh, V. Safoora, Phys. Rev. C, **94**, 024623 (2016); Phys. Rev. C **95**, 064611 (2017); Phys. Rev. C **96**, 034610 (2017); Eur. Phys. J. A **53**, 229 (2017); Eur. Phys. J. A **54**, 80 (2018).