Evaporation residue cross section for the reaction ^{48}Ca+^{243}Am→^{291}Mc

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Introduction

Using hot and cold fusion reactions, super heavy elements up to Z=118 have been prepared in the laboratory and attempts to produce Z=119 and Z=120 have been done. The production cross section for the synthesis of SHE depends on the entrance channel Coulomb barrier, center of mass energy, excitation energy, probability of CN formation, fission barrier, survival probability etc. In the formation of SHE, initially the projectile and target combine, form an excited compound nucleus, then this CN cools down by the evaporation of neutrons and form evaporation residue.

In the present work our aim is to predict the evaporation residue cross section for the synthesis of Z=115 (Mc) using the reaction ^{48}Ca+^{243}Am.

Theory

2.1. 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.

2.2. 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, approximating the barrier by a parabola.

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

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 [3] 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, 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, Δ is an adjustable parameter ($\Delta = 4MeV$) and x_{eff} is the effective fissility defined as:

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

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. To calculate, Vandenbosch and Huizenga have suggested a classical formalism to calculate Γ_n/Γ_f:

$$\frac{\Gamma_n}{\Gamma_f}=\frac{4A^{2/3}a_f(E^*-B_n)}{K_0a_n[2a_f^{1/2}(E^*-B_f)^{1/2}-1]}\times \exp[2a_n^{1/2}(E^*-B_n)^{1/2}-2a_f^{1/2}(E^*-B_f)^{1/2}] \quad (11)$$

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 Discussions

Interaction barrier for the fusion reactions ^{48}Ca+^{243}Am is shown in Fig. 1 (a). The entrance channel Coulomb barrier is calculated by using the Coulomb and proximity potential as the interaction barrier. The probability of compound nucleus formation as a function of center of mass energy is plotted in Fig. 1 (b). The capture cross section is calculated using the well known Wong formula. The fusion cross section is calculated by using the value of P_{CN}. In Fig. 3 (a), we present the capture and fusion excitation function for the reaction ^{48}Ca+^{243}Am leading to SHE ^{291}Mc. We have calculated the ER excitation functions in 2n, 3n, 4n and 5n channel. The calculated maximum value of 2n, 3n, 4n and 5n channel cross section is 1.11pb (E*=32.11 MeV), 7.65pb (E*=33.61 MeV), 2.60pb (E*=39.11 MeV) and 0.05pb (E*=50.61 MeV) respectively. Using this reaction experimentally Oganessian et al, [4] measured the production cross section for 3n and 4n channel. In Fig.3 (b), we present our calculated value of ER cross section at different excitation energies. Our values are in good with experimental value within the error bars. This proves the effectiveness of our calculation.

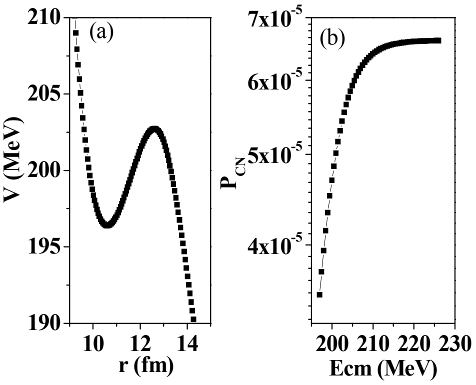

Fig.1 (a) Interaction barrier and (b) probability of compound nucleus formation P_{CN} for the fusion reaction ^{48}Ca+^{243}Am.

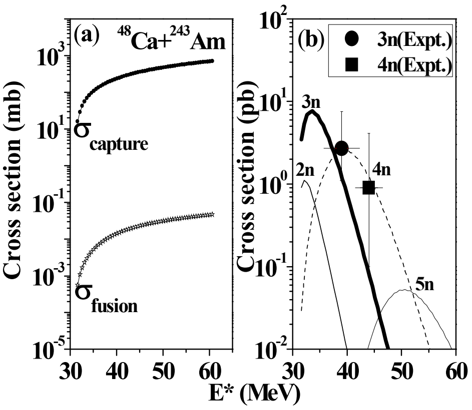

Fig.2 (a) Capture and fusion cross section (b) ER cross section for the reaction ^{48}Ca+^{243}Am.

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