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# Cl, K and Ni induced reactions to synthesis SHN $^{273}$Rg

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We have studied chlorine (Cl), potassium (K) and Nickel (Ni) induced reactions in the synthesis of $^{273}$Rg. We have studied the compound nucleus formation probability, survival probability and evaporation residue cross sections to synthesize superheavy element (SHN) $^{273}$Rg. The selected projectile-target combinations to synthesis $^{273}$Rg are $^{35,37}$Cl + $^{238,236}$Pu, $^{39-41}$K + $^{234-232}$U and $^{63,64}$Ni + $^{210,209}$Bi. From the study of $P_{CN}$, $P_{sur}$ and $\sigma_{evr}$ we have identified that $^{35}$Cl+$^{238}$Pu is the most suitable projectile-target combination to synthesize $^{273}$Rg. We have also compared the present work with the experimental values available in literature.

**Keywords:** Superheavy nuclei, Compound nucleus formation probability, Evaporation residue cross sections, Survival probability

## 1 Introduction

In the latest years, the synthesis of superheavy element either by cold fusion reaction or by hot fusion reaction has been achieved with the much progress. The cold fusion reactions are carried with lead and bismuth targets and hot fusion reactions with actinide targets. Earlier workers[1-4] experimentally studied the possibility of synthesis and investigation of the superheavy nuclei in the "island of stability". The experiments in the superheavy region requires a strong support of theoretical background which will let more accurate choice of fusion reactions, excitation functions and well estimation of cross sections. Many theoretical models[5-14] were described how accurately these superheavy elements can be synthesised, how accurately the predicted cross sections agrees well with the experimental values and also anticipated the fusion cross sections in the region where no experimental data are available. Generally there are three important stages in the formation of superheavy element, i.e., capture cross section by overcoming coulomb barrier, formation of compound nucleus and de-excitation process against fission.

Previous workers[15-19] predicted the production cross sections in the superheavy region. The large survival probability of compound nucleus formation results in small neutron separation energy. Previous workers[20-24] predicted the possible projectile-target combinations to synthesis the superheavy element. Hofmann *et al.*[25-26] synthesised $^{272}$111 from the fusion of $^{64}$Ni+$^{209}$Bi. Morita *et al.*[27] observed consistent decay alpha decay chains in superheavy nuclei $^{272}$Rg. From the available literature, we have observed only few experimental and theoretical work on superheavy nuclei $^{273}$Rg. In order to examine the synthesis of superheavy nuclei $^{273}$Rg, for the first time we made an attempt to identify maximum compound nucleus formation ($P_{CN}$), survival probability ($P_{sur}$) and evaporation residue cross sections ($\sigma_{evr}$) using the different projectiles such as chlorine (Cl), potassium (K) and nickel (Ni).

## 2 Theoretical Framework

The effective interaction between projectile and target is the sum of coulomb potential, proximity potential and centrifugal potential. For the proximity potential part we have used the equations defined by earlier workers[28]. Later we studied the fusion barrier height $V_B$ and barrier position $R_B$ using the following boundary conditions:

$$\left.\frac{dV(r)}{dr}\right|_{r=R_B} = 0 \text{ and } \left.\frac{d^2V(r)}{dr^2}\right|_{r=R_B} \le 0 \quad \dots (1)$$

The fusion cross sections were studied using Wong model[29]. The cross section for the fusion of projectile with target is given by:

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$$\sigma_{fus} = \frac{\pi\hbar^2}{2\mu \times E_{cm}} \sum_{l=0}^{l_{max}} (2l+1) \times T_l(E_{cm}) P_{CN}(E_{cm}, l) \quad \ldots (2)$$

where μ is the reduced mass, $E_{cm}$ is the center of mass energy, $l_{max}$ largest partial wave packet, $T_l$ ($E_{cm}$) energy depended barrier penetration factor and $P_{CN}$ probability for compound nucleus formation. The compound nucleus formation probability is given as:

$$P_{CN}(E,J) \approx P_{CN}(E) = 0.5 \exp\left[-c\left(\chi_{eff} - \chi_{thr}\right)\right] \quad \ldots (3)$$

In this equation $c$ and $\chi_{thr}$ are the adjustable fitting parameters whose values for cold fusion reactions are 136.5 and 0.79, respectively, and for hot fusion reactions the fitting constants are 104 and 0.69, respectively. $\chi_{eff}$ is the effective fissility and it is in detail explained in the previous work[24]. The evaporation residue cross sections[30] with the release of neutrons is studied using the equation:

$$\sigma_{ER}^{x} = \frac{\pi}{k^2} \sum_{l=0}^{\infty} (2l+1) T(E,l) P_{CN}(E,l) P_{sur}^{xn}(E^*, l) \quad \ldots (4)$$

where $P_{sur}$ is the survival probability of the compound nucleus against the decay by the evaporation of neutrons or light particles and it is investigated using the relation:

$$P_{sur} = P_{xn}\left(E_{CN}^*\right) \prod_{i=1}^{i_{max}=x} \left(\Gamma_n / \Gamma_n + \Gamma_f\right)_{i,E^*} \quad \ldots (5)$$

where $P_{xn}$ is the probability of evaporation of x neutrons from compound nucleus [30,31] and "i" is equal to the number of emitted neutrons. The ratio of neutron emission width to fission width is given by [32] and it is determined by the following equation:

$$\frac{\Gamma_i}{\Gamma_f} = \frac{4A^{2/3} a_f \left[E_{CN}^* - B_i\right]}{k a_n \left\{2\sqrt{a_f \left[E_{CN}^* - B_f\left(E_{CN}^*\right)\right]} - 1\right\}} \times \exp\left\{\begin{array}{l} 2\sqrt{a_n \left[E_{CN}^* - B_i\right]} \\ -2\sqrt{a_f \left[E_{CN}^* - B_f\left(E_{CN}^*\right)\right]} \end{array}\right\} \quad \ldots (6)$$

where $k$ = 9.8 MeV, $a_n$ is the level density parameter of neutron evaporation channel $a_f$ is the level density parameter for fission repectively. $B_f$ is the fission barrier and these values are taken as suggested in the earlier work[22].

## 3 Results and Discussion

We have studied fusion reactions for the synthesis of the selected superheavy nuclei $^{273}$Rg. We have used projectile such as chlorine ($^{35,37}$Cl), potassium ($^{39,40}$K) and nickel ($^{63,64}$Ni) with the targets such as plutonium ($^{238,236}$Pu), uranium ($^{234,233}$U) and bismuth ($^{210,209}$Bi). Although they are many combinations, but those combinations of fusion reactions are difficult to synthesis due to less survival probability and lesser compound nucleus formation probability. Hence in the present work we studied only chlorine, potassium and nickel fusion reactions. For the above said projectile-target combinations, we have studied survival probability ($P_{sur}$) and compound nucleus formation probability ($P_{CN}$) and evaporation residue cross sections ($\sigma_{evr}$). A comparison of compound nucleus probability ($P_{CN}$) with different projectile-target combinations are as shown in Fig. 1. From the figure it is clearly observed that the compound nucleus probability is maximum for $^{35}$Cl+ $^{238}$Pu at 25MeV when compared to all other combinations. The study on the survival probability of compound nucleus against different decay modes gives the information on the stability of the nuclei. Hence the study of the survival probability of compound nucleus for different projectile-target combinations are shown in Fig. 2. Figure 2 shows maximum survival probability for $^{35}$Cl+ $^{238}$Pu at 25MeV. We have studied evaporation residue cross sections ($\sigma_{evr}$) of the projectiles such as chlorine ($^{35,37}$Cl), Potassium ($^{39,40}$K) and Nickel ($^{63,64}$Ni) with the targets such as Plutonium ($^{238,236}$Pu), Uranium ($^{234,233}$U) and bismuth ($^{210,209}$Bi). The studied

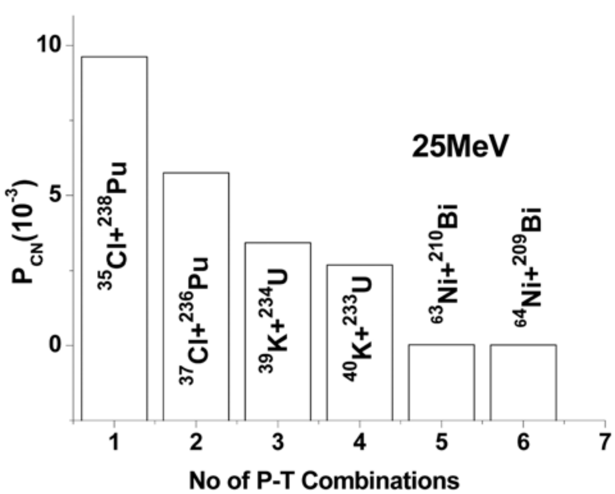


Fig. 1 — A comparison of compound nucleus probability ($P_{CN}$) with different projectile-target combinations at 25MeV.

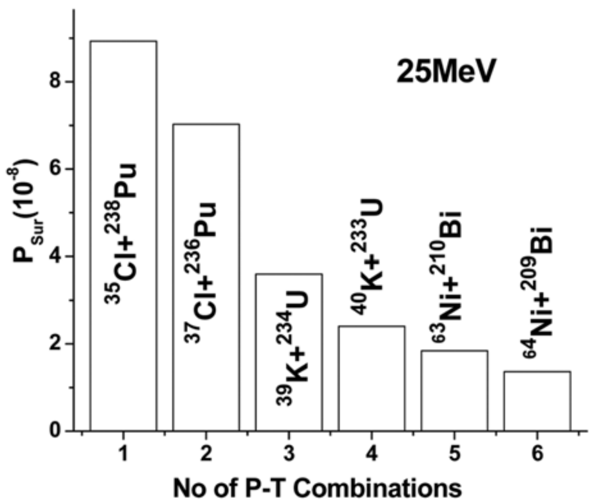


Fig. 2 — A comparison of survival probability ($P_{sur}$) with different projectile-target combinations at 25 MeV.

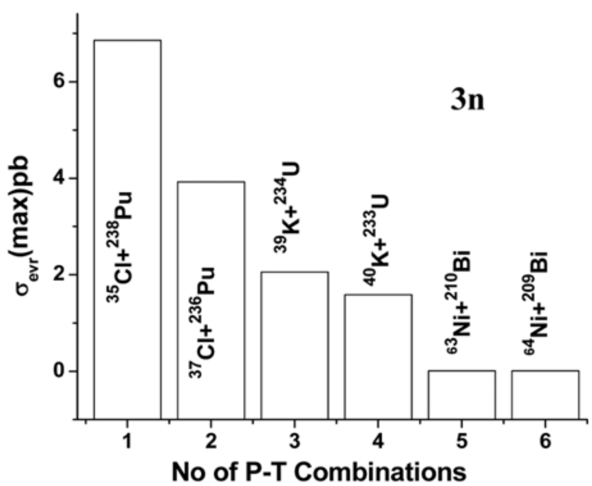


Fig. 3 — A comparison of maximum evaporation residue cross sections for different projectile-target combinations.

maximum evaporation cross sections of the above said projectile-target combinations are shown in Fig. 3. From the analysis of the figure, it is observed that the projectile and target combination $^{35}Cl+ ^{238}Pu$ is having maximum evaporation residue cross section for 3n evaporation and it is also compared with the other studied combinations. The comparison of experimental fusion cross sections with the present work is shown in the Table 1. From the table it is observed that the calculated cross sections of 1n evaporation is comparable with the experimental values. The table also gives the calculated cross sections of $^{35}Cl+ ^{238}Pu$. The calculated evaporation residue cross sections of the $^{35}Cl+ ^{238}Pu$ for 3-5 neutron evaporation is as shown in the Fig. 4.

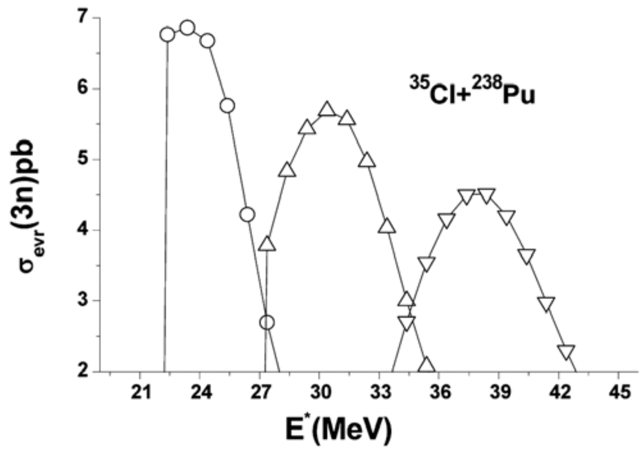


Fig. 4 — Evaporation residue cross section as a function of E∗ for projectile-target combination $^{35}Cl+ ^{238}Pu$.

Table 1 — A comparison of experimental fusion cross sections with the present work.

| Projectile | Target | CN | Cross section exp [25,26] | Cross section Present work |
|---|---|---|---|---|
| $^{64}Ni$ | $^{209}Bi$ | $^{273}Rg$ | $3.5^{+4.6}_{-2.3}$ pb, 12.5 MeV (1n) | 2.56 pb 12.98 MeV (1n) |
| | | | $1.7^{+3.3}_{-1.4}$ pb, 11 MeV (1n) | 5.86 pb 11.958 MeV (1n) |
| | | | < 2.9 pb, 9.4 MeV (1n) | 2.5 pb 9.8 MeV (1n) |
| $^{35}Cl$ | $^{238}Pu$ | $^{273}Rg$ | --------- | 6.859 pb, 23.4MeV (3n) |
| | | | --------- | 6.63563 pb 11.4 MeV (1n) |
| | | | --------- | 5.687 pb 30.38 MeV (4n) |

## 4 Conclusions

From the study of compound nucleus formation probability, survival probability and evaporation residue cross sections for SHN $^{273}Rg$, we have identified that the $^{35}Cl+^{238}Pu$ is having maximum compound nucleus probability, survival probability and evaporation residue cross sections compared to other combinations. Thus employing results, one can produce superheavy nuclei $^{273}Rg$ from the fusion of $^{35}Cl+ ^{238}Pu$ than synthesising the superheavy nuclei by the fusion $^{64}Ni+^{209}Bi$.

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