# Decay cross sections of excited compound system $^{39}K^*$ and $^{40}Ca^*$ formed in heavy ion reactions

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## Introduction

The systematic and dynamics of collisions between heavy ions and the decay of the compound nucleus (CN) exhibit a number of interesting characteristics which deserve further experimental and theoretical investigations. For collisions between light heavy ions ($A_p$, $A_t < 40$) the kinetic energy of the fragments contains significant centrifugal energy contributions.

Experiments [1] have been performed for the synthesis of hot and rotating compound nuclei $^{40}Ca^*$ formed through the entrance channel $^{12}C$ + $^{28}Si$ ($E_{cm}$=53.9MeV) and $^{39}K^*$ formed through the entrance channels $^{11}B$ + $^{28}Si$ ($E_{cm}$=45.9MeV) and $^{12}C$ + $^{27}Al$ ($E_{cm}$=50.5MeV). In the present manuscript, as an extension of our previous work on $^{48}Cr^*$ [2] the decay cross section for the decay of $^{40}Ca^*$ and $^{39}K^*$ has been evaluated at various $E_{cm}$ values, including these experimental $E_{cm}$ values. The calculations have been done for spherical fragmentation at same excitation energy, $E_{CN}^*$=66.5MeV (equivalently T=4.0MeV), taking the scattering potential as the sum of Coulomb potential and proximity potential of Blocki et al, [3].

## Theory

The interaction barrier for two colliding nuclei is given as,

$$V=\frac{Z_1Z_2e^2}{r}+V_P(z)+\frac{\hbar^2\ell(\ell+1)}{2\mu r^2} \qquad (1)$$

where $V_P(z)$ represents the proximity potential given as,

$$V_P(z)=4\pi\gamma b\frac{C_1C_2}{C_1+C_2}\phi(\frac{z}{b}) \qquad (2)$$

where $\phi(z/b)$ is the universal proximity potential of Blocki et.al, with $z$, the distance between the near surfaces of the projectile and target, $\ell$ the angular momentum, $\mu$ the reduced mass, $Z_1$, $Z_2$ the atomic numbers of projectile and target and $r$ is the distance between centers of the projectile and target.

The CN decay cross section has been derived by Wong [4] within the quantum mechanical penetration of one dimensional potential barrier using the probability for absorption of $\ell^{th}$ partial wave given by Hill-Wheeler formula for energy $E_\ell$ which is given as

$$\sigma=\frac{\pi}{k^2}\sum_\ell\frac{2\ell+1}{1+\exp[2\pi(E_\ell-E)/\hbar\omega_\ell]} \qquad (3)$$

where $k=\sqrt{2\mu E/\hbar^2}$ . Here $\hbar\omega_\ell$ is the curvature of the inverted parabola.

Using some parameterizations in the region $\ell=0$ and sum being replaced by integration Wong derived the cross section as

$$\sigma=\frac{R_B^2\hbar\omega_0}{2E}\ln\left\{1+\exp\left[\frac{2\pi(E-E_B)}{\hbar\omega_0}\right]\right\} \qquad (4)$$

where $R_B$ is the barrier radius and $E_B$ is the barrier height.

For relatively large values of $E$, the above result reduces to

$$\sigma=\pi R_B^2\left[1-\frac{E_B}{E}\right] \qquad (5)$$

Glas and Mosel [5] put forward a relation for cross section σ as

$$\sigma=\pi\lambda\!\!\!^{-2}\sum_{\ell=0}^{\infty}(2\ell+1)T_iP_i \qquad (6)$$

where $T_i$ is the penetration probability and

$$P_i=\begin{cases}1, \ell\le\ell_c\\ 0, \ell\rangle\ell_c\end{cases} \qquad (7)$$

Replacing the sum in Eq. (6) by integration, one obtains the cross section as

$$\sigma=\frac{\hbar\omega}{2}R_B^2\frac{1}{E}\ln\left\{\frac{1+\exp[2\pi\{E-V(R_B)\}/\hbar\omega]}{1+\exp[2\pi\{E-V(R_B)-(R_c/R_B)^2[E-V(R_c)]\}/\hbar\omega]}\right\} \qquad (8)$$

where $R_C$ is the critical distance, $V(R_C)$ is the corresponding potential height.

## Results and Discussions

The cross sections for the decay of light mass nuclei $^{40}Ca^*$ formed through the entrance channel $^{12}C$ + $^{28}Si$ and $^{39}K^*$ formed through the asymmetric channels $^{11}B+^{28}Si$ and $^{12}C+^{27}Al$ have been investigated. The interaction barrier for $^{12}C+^{28}Si$, $^{11}B+^{28}Si$ and $^{12}C+^{27}Al$ reactions were plotted against distance between the centers of projectile and target corresponding to $\ell$=0. The cross section is calculated using Equations (4), (5) and (8) for various $E_{cm}$ values above the barrier.

**Table 1:** The decay cross sections for $^{40}Ca^*$ and $^{39}K^*$ for various $E_{cm}$ values.

| Channels | $E_{cm}$ (MeV) | CN decay cross section σ (mb) | |
|---|---|---|---|
| | | Eq. (5) | Eq. (8) |
| $^{11}B+^{28}Si$ | 34 | 1693.31 | 1349.32 |
| | 40 | 1805.07 | 1307.46 |
| | 45.9 | 1886.48 | 1276.97 |
| | 52 | 1951.22 | 1252.72 |
| | 58 | 2001.62 | 1233.84 |
| $^{12}C+^{27}Al$ | 38 | 1670.49 | 129381 |
| | 44 | 1771.35 | 1264.82 |
| | 50.5 | 1853.57 | 1241.19 |
| | 56 | 1908.23 | 1225.48 |
| | 62 | 1956.80 | 1211.52 |
| $^{12}C+^{28}Si$ | 35 | 1495.63 | 1296.48 |
| | 41 | 1617.54 | 1267.35 |
| | 53.9 | 1787.73 | 1226.66 |
| | 59 | 1834.49 | 1215.49 |
| | 65 | 1880.11 | 1204.58 |

In table 1, we have given the decay cross sections for the light mass nuclei $^{40}Ca^*$ formed through the asymmetric channel $^{12}C+^{28}Si$ and $^{39}K^*$ formed through the entrance channels $^{11}B+^{28}Si$ and $^{12}C+^{27}Al$.

The Fig.1 represents the plot of interaction barrier versus distance between the centers of projectile and target for the combinations $^{11}B+^{28}Si$, $^{12}C+^{27}Al$ and $^{12}C+^{28}Si$ for the experimental $E_{cm}$ values corresponding to $\ell$=0.

Fig. 2 represents the plot for the calculated decay cross sections in logarithmic scale plotted against various $E_{cm}$ values, $^{40}Ca^*$ formed through the entrance channel $^{12}C$ + $^{28}Si$ and $^{39}K^*$ formed through the asymmetric channels $^{11}B+^{28}Si$ and $^{12}C+^{27}Al$. The decay cross sections, evaluated using Eq. (4), (5) and (8), corresponding to the experimental $E_{cm}$ has also been plotted in these figures. As, it was observed from our previous work on $^{48}Cr^*$ [2], that the decay cross section matches well with the experimental values, we hope that the present study will be a guide for the future experiments.

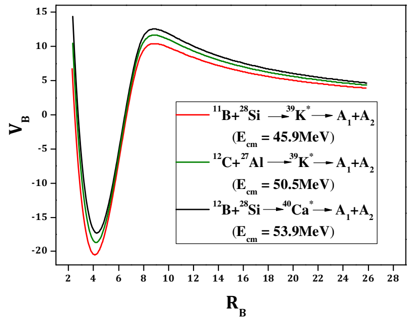


**Fig 1:** The interaction barrier for (a) $^{11}B+^{28}Si \rightarrow ^{39}K^*$ (b) $^{12}C+^{27}Al \rightarrow ^{39}K^*$ and (c) $^{12}C+^{28}Si \rightarrow ^{40}Ca^*$.

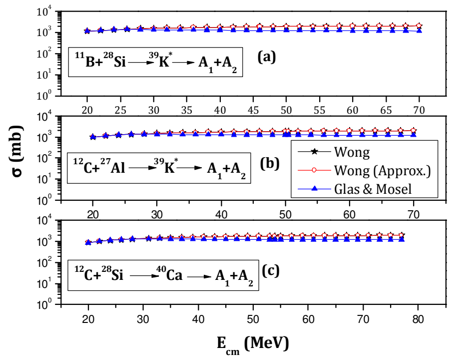


**Fig 2:** The decay cross sections for $^{40}Ca^*$ and $^{39}K^*$ for various $E_{cm}$ values.

## References

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