

# Analysis of fusion enhancement for isotopic chain of neutron-rich light mass compound nuclei formed in $^{12-15}\text{C}+^{12}\text{C}$ reactions

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## Introduction

The reaction mechanism of neutron-rich light mass compound nuclei (CN)  $^{24-27}\text{Mg}^*$  formed in  $^{12-15}\text{C}+^{12}\text{C}$  fusion reactions at  $E_{c.m.}\sim 10.37$  MeV, respectively, is studied within the quantum mechanical fragmentation theory based dynamical cluster decay model (DCM) [1, 2]. These reactions also play an important role in astrophysical scenarios as we know that after helium burning, a large concentration of  $^{12}\text{C}$  in the core of massive stars leads to carbon burning carried by the  $^{12}\text{C}+^{12}\text{C}$  fusion reactions. Also, the  $^{12}\text{C}+^{12}\text{C}$  fusion reaction is the primary route for the nucleosynthesis of heavier elements and a crucial process in the later phases of stellar evolution and explosions [3]. The carbon fusion reaction is also considered to be responsible for igniting stellar explosions such as core-collapse supernovas and x-ray super-bursts. X-ray super-bursts are the recently observed explosive phenomenon, which is the brightest, most energetic, and rare explosions considered to be triggered by the unstable  $^{12}\text{C}+^{12}\text{C}$  fusion in the crust of neutron stars [4].

The exploration of the dynamics and cross-sections of these low-energy neutron-rich carbon reactions are one of the most important topics for understanding a number of astrophysical scenarios. But the presence of unpredictable  $^{12}\text{C}+^{12}\text{C}$  resonance structures results in large uncertainties in their astrophysical cross sections [5]. In comparison to these resonances, other carbon isotope fusion reactions such as  $^{12}\text{C}+^{13}\text{C}$  behave more regularly. The resonance structures in low-energy carbon fusion reactions were studied with the correlation to the carbon isotope fusion reactions [6]. The investigations of the fusion for an isotopic chain of neutron-rich nuclei are important, as the Coulomb potential of the neutron-rich projectile is largely unaffected by adding neutrons. We have recently investigated the dynamical aspects associated with reactions involving neutron-rich isotopic chains of reactions  $^{39,40,41,45,46,47}\text{K}+^{28}\text{Si}$  within the DCM [1]. The result explore that the fusion enhancement is larger for odd neutron number nuclei as compared to adjacent

neutron nuclei and indicates the influence of unpaired neutrons on fusion cross-sections. This work was for the neutron-rich mid-mass systems  $^{67-69,73-75}\text{As}^*$ , now we shifted to the lower mass region of  $^{12-15}\text{C}+^{12}\text{C}$  induced  $^{24-27}\text{Mg}^*$  CN. The total fusion cross sections of these neutron-rich light mass carbon isotopes have been measured recently by using the newly developed MUSIC detector [7].

## Methodology

Based on the fragmentation potential at fixed relative separation  $R$  and temperature  $T$ , and the scattering potential at fixed  $\eta = (A_1-A_2)/(A_1+A_2)$  and  $T$ , we calculate the compound nucleus decay cross-section by using the DCM, worked out in terms of the decoupled collective coordinates of mass (and charge) asymmetry  $\eta$  [ $\eta_Z = (Z_1-Z_2)/(Z_1+Z_2)$ ] and  $R$ . In terms of these coordinates, using  $l$  partial waves, the compound nucleus decay cross-section is defined as

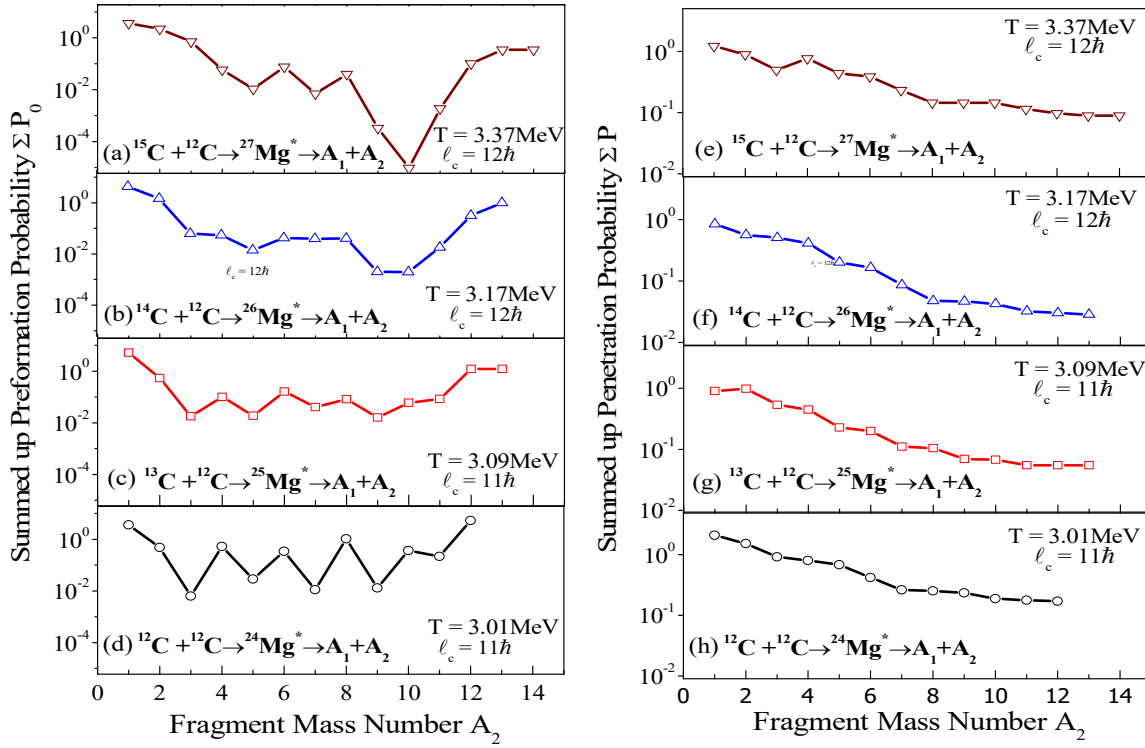
$$\sigma = \frac{\pi}{k^2} \sum_{l=0}^{l_{\max}} (2l+1) P_0 P; \quad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

where the preformation probability  $P_0$ , referring to  $\eta$  motion, is the solution of stationary Schrödinger equation in  $\eta$  coordinate at a fixed  $R$ , and  $P$ , the WKB penetrability, refers to  $R$  motion. Both the quantities, i.e.,  $P_0$  and  $P$  carry the effects of  $T$  and angular momentum  $l$  of colliding nuclei at a given  $E_{c.m.}$ . Here,  $\mu = [A_1 A_2 / (A_1 + A_2)] m$ , is the reduced mass, with  $m$  as the nucleon mass.

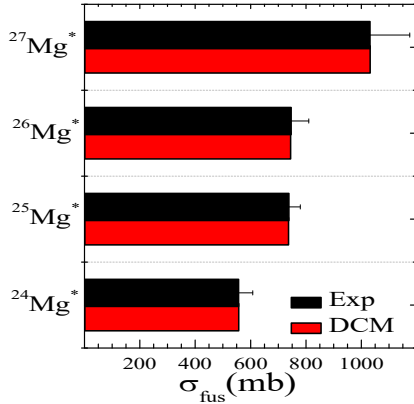
## Results and Discussions

Fig. 1(a-d) presents  $l$ -summed up preformation probability  $\Sigma P_0$  as a function of  $A_2$  for CN  $^{27,26,25,24}\text{Mg}^*$  at  $E_{c.m.}\sim 10.37$  MeV calculated for respective  $l_c$ -values. The  $\Sigma P_0$  of light particles LPs ( $A \leq 4$ ) in  $^{25}\text{Mg}^*$  is more as compared to  $^{24}\text{Mg}^*$ . That is, we observe an enhancement in the yield of unpaired compound system (CS) as moving from paired CS. This enhancement is very small as we move to paired CS  $^{26}\text{Mg}^*$  from unpaired CS  $^{25}\text{Mg}^*$  due to the almost equal contribution of LPs. The LPs  $1n$  and  $^4\text{He}$  have higher  $\Sigma P_0$  in  $^{25}\text{Mg}^*$  but LPs  $2n$  and  $^3\text{H}$  have higher contribution in  $^{26}\text{Mg}$ . Again moving from 1(b) to 1(a), i.e., paired to unpaired CS, there is an enhancement in  $\Sigma P_0$  of LPs in  $^{27}\text{Mg}^*$

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**Fig. 1 (a,b,c,d)** The summed up preformation probability  $\Sigma P_0$  and **(e,f,g,h)** the summed up penetration probability  $\Sigma P$ , with fragment mass no.  $A_2$  for the decay of  $^{27,26,25,24}\text{Mg}^*$  compound nuclei.



**Fig. 2** The DCM calculated fusion cross section  $\sigma_{\text{fus}}$ (mb) in comparison with the experimental data [7].

with a major contribution of LPs 1n, 2n, 3n. We also observed a higher contribution of symmetric and near symmetric fragments, which goes on decreasing with increasing mass of CN. Fig. 1(e-h) presents  $l$ -summed up penetrability  $\Sigma P$  as a function of  $A_2$  for CN  $^{27,26,25,24}\text{Mg}^*$  at  $E_{\text{c.m.}} \sim 10.37$  MeV calculated for respective  $\ell_c$  values. Here, the  $\Sigma P$  is large mainly for the LPs, and consequently, with the large  $\Sigma P_0$  they contributed more towards the fusion yield. Here, the results do not show any specific trends as observed for  $\Sigma P_0$ . The DCM calculated  $\sigma_{\text{fus}}$ (mb), shown by red bars,

for the compound nuclei  $^{24-27}\text{Mg}^*$ , at  $E_{\text{c.m.}} \sim 10.37$  MeV, are in a very good agreement with the available experimental data [7].

Fig. 2 clearly elaborates the phenomenon of fusion enhancement as we see that the cross sections of CS  $^{25}\text{Mg}^*$  are larger than CS  $^{24}\text{Mg}^*$ , in comparison to CS  $^{26}\text{Mg}^*$ . Furthermore, the CS  $^{27}\text{Mg}^*$  has fusion enhancement, in comparison to CS  $^{26}\text{Mg}^*$ . This is important to note that this observation is consistent with  $\Sigma P_0$  enhancement within the collective clusterization approach of DCM i.e. it comes naturally within this dynamical expression of low energy heavy ion reactions forming light mass composite systems. The effects of variation in the values of  $E_{\text{c.m.}}$  on the reaction dynamics will be presented during the symposium.

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