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*Role of pairing coefficient in the dynamics of compound nuclei $^{24,25}Mg$**

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Introduction

- The decay for number of compound nuclei formed in low energy heavy ion reactions have been successfully studied using dynamical cluster decay model (DCM) [R. K. Gupta et al., J. Phys. G: Nucl. Part. Phys. 31, 631 (2005); 32, 345 (2006); J. Phys. G: Nucl. Part. Phys. 37, 115103 (2010), Nucl. Phys. A 980, 67 (2018) Phys. Rev. C 99, 014614 (2019)].

- In previous study the decay of $^{25,24}Mg^{*}$ compound nuclei (CN) formed in the $^{13,12}C+^{12}C$ reactions have been explored [Rupinder Kaur, Sarbjeet Kaur et al., Phys. Rev. C 101, 034614 (2020)] within DCM. The role of α-cluster structure of the complimentary fragments was explored, which results in the enhanced preformation probability (P_0) with respect to other fragments. These enhanced P_0 values accordingly affect the yields of the respective intermediate mass fragment (IMF).

- In the present study, we have extended this work to study the effect of pairing coefficient to the fragmentation and preformation profile of the experimentally observed IMFs that are $^{6,7}Li$ and $^{7,8,9}Be$ in the decay of $^{24,25}Mg^{*}$ CN.

Methodology

- To study ground state emissions of nucleus and emissions of excited compound nucleus in heavy ion reactions, Gupta and collaborates developed the dynamical (or quantum mechanical) fragmentation theory, in the form of PCM [*R. K. Gupta et al; Phys. Rev. C* ***79****, 064616 (2009);* ***83****, 064610 (2011)*] and DCM [*R. K. Gupta et al., Phys. Rev. C* ***77****, 054613 (2008);* ***85****, 024604 (2012)*], which uses collective coordinates of Quantum Mechanical Fragmentation Theory(QMFT):

  - The mass and charge asymmetries $\eta = \frac{(A_1 - A_2)}{(A_1 + A_2)}$ and $\eta_z = \frac{(Z_1 - Z_2)}{(Z_1 + Z_2)}$.
  - Deformations $\beta_{\lambda i}$, orientations θ_i of two fragments.
  - Relative separation co-ordinate R.

For the ground state decay (T=0, $\ell=0$) of nucleus, the decay constant λ_{PCM} is defined as

$$\lambda_{PCM} = \frac{\ln 2}{T_{1/2}} = \nu_0 P_0 P,$$

Using the partial wave analysis, for the hot and rotating (T≠0 and $\ell\neq0$) compound nucleus , the decay cross-section is defined as

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P \qquad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2_4}}$$

Methodology

The preformation probability is given by

$$P_0[=|\ \psi_R(\eta(A_i))\ |^2\ \sqrt{B_{\eta\eta}}\frac{2}{A^*_{CN}}]$$

which we get by solving Schrödinger equation in η-coordinates

$$[-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta} + V_R(\eta, T)]\psi_R^{(\nu)}(\eta) = E_R^{(\nu)}\psi_R^{(\nu)}(\eta)$$

Where $V_R(\eta, T)$ is the fragmentation potential and is defined as:

$$V(\eta, R, \beta, \theta, T) = \sum_{i=1}^{2}[V_{LDM}(A_i, Z_i, T)] + \sum_{i=1}^{2}[\delta U]\, e^{(-\frac{T^2}{T_0^2})} + V_c(R, Z_i, \beta_{\lambda i}, \theta_i, T) + V_P(R, Z_i, \beta_{\lambda i}, \theta_i, T) + V_\ell(R, Z_i, \beta_{\lambda i}, \theta_i, T, \ell)$$

V_C, V_P and V_l are respectively the temperature dependent Coulomb, nuclear proximity and angular momentum dependent potentials.

P is the penetrability, refers to the R-motion, calculated by the WKB approximation

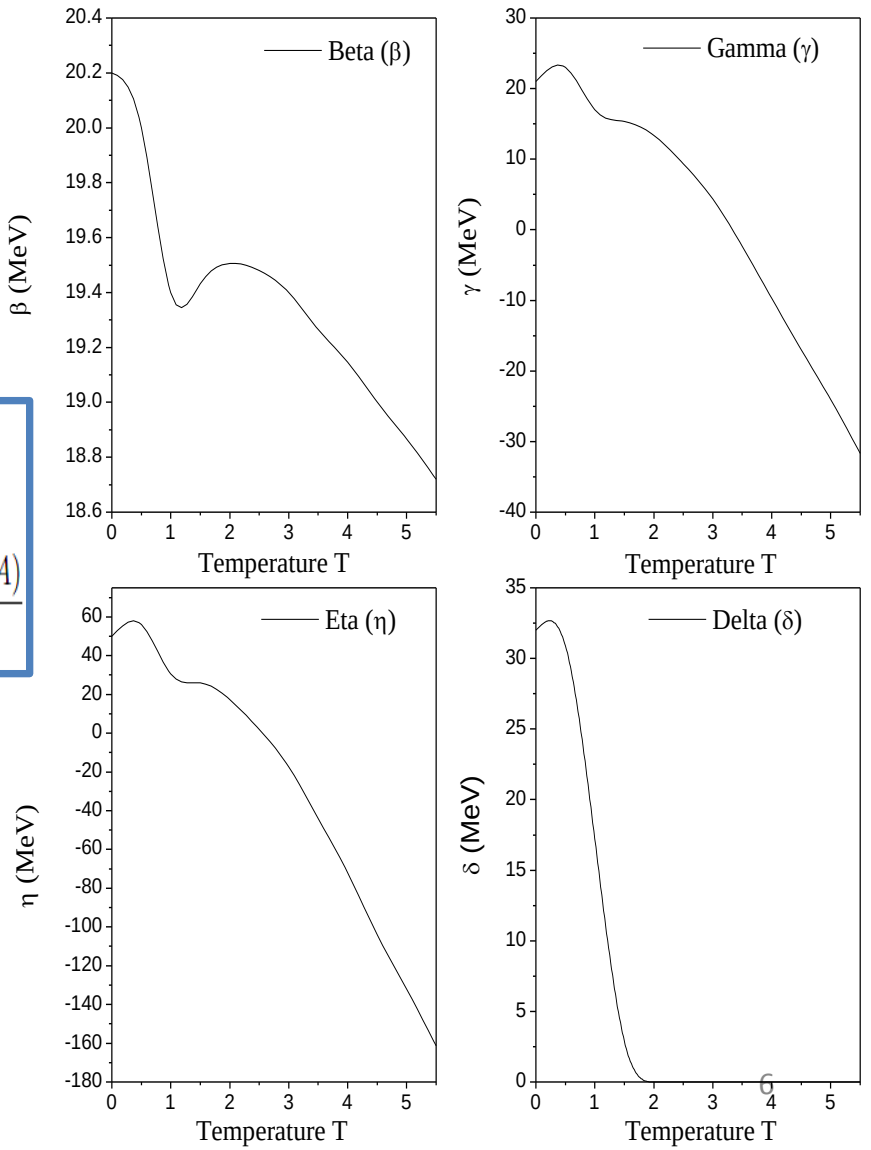
$$P = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_b}\{2\mu[V(R,T) - V(R_a,T)]\}dR\right]$$

Methodology

- In DCM the T- dependent liquid drop part of Binding energy $V_{LDM}(T)$ is taken from Davidson et.al [Davidson, NPA 570, 61c (1994)], based on the semi-empirical mass formula of Seeger [P.A. Seeger, NPA 25,1 (1961)], is

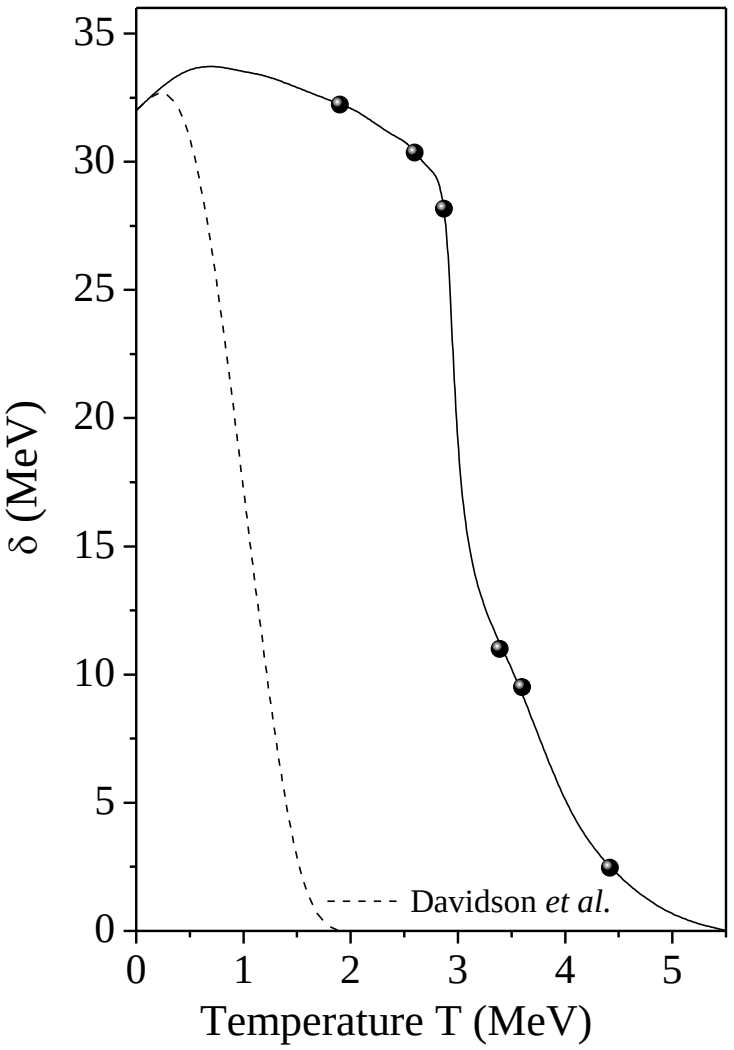
$$V_{LDM}(A,Z,T) = \alpha(T)A + \beta(T)A^{\frac{2}{3}} + \left(\gamma(T) - \frac{\eta(T)}{A^{\frac{1}{3}}}\right)\left(\frac{I^2 + 2\,|\,I\,|}{A}\right) + \frac{Z^2}{R_0(T)A^{\frac{1}{3}}}\left(1 - \frac{0.7636}{Z^{\frac{2}{3}}} - \frac{2.29}{[R_0(T)A^{\frac{1}{3}}]^2}\right) + \delta(T)\frac{f(Z,A)}{A^{\frac{3}{4}}}$$

- The $\alpha(T)$, $\beta(T)$, $\gamma(T)$, $\eta(T)$ and $\delta(T)$ were obtained numerically by Davidson, as shown in Figure for T $\leq$ 5.5 MeV.
- For the bulk constant $\alpha(T)$, instead, an empirically fitted expression to a Fermi gas model is used.

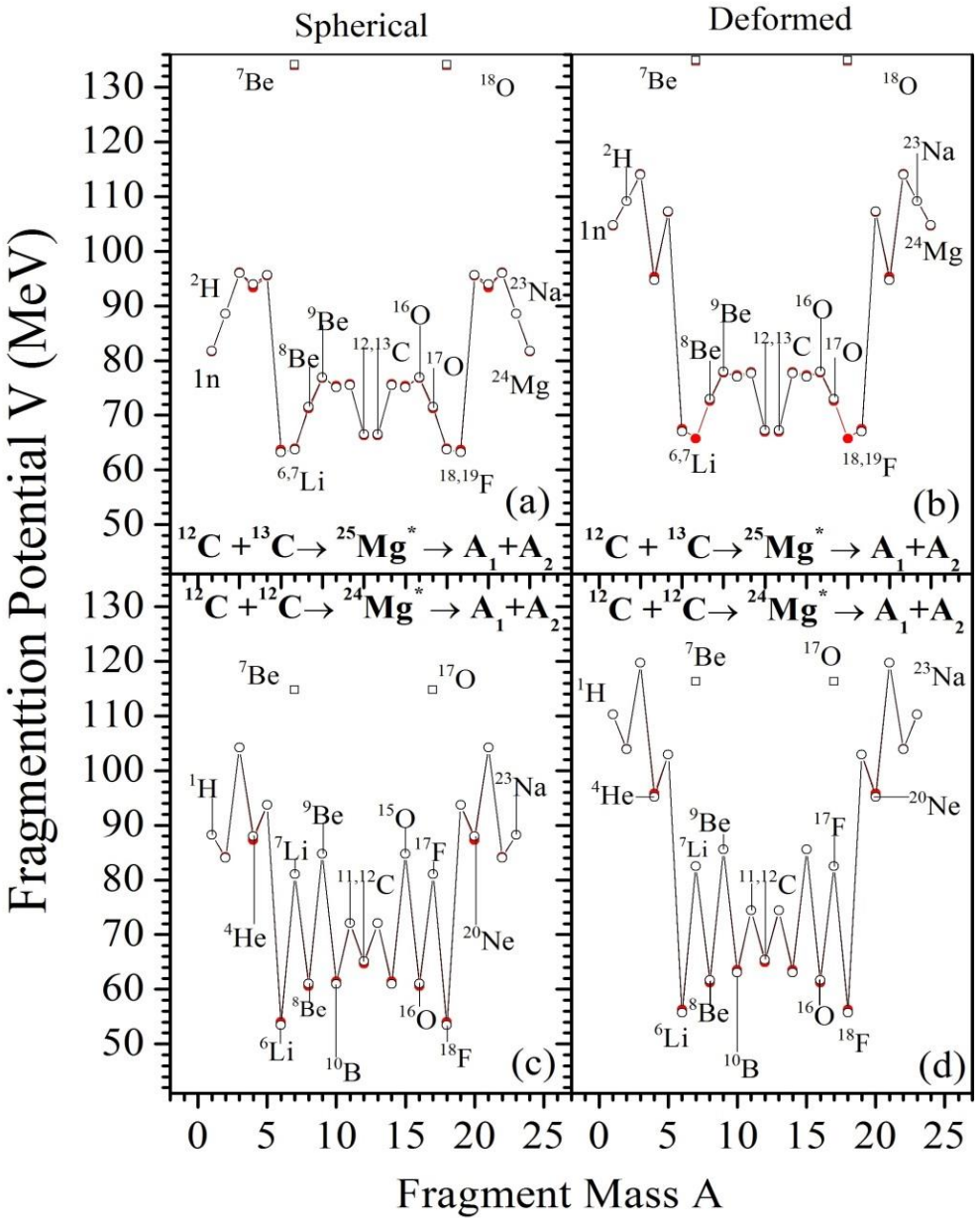


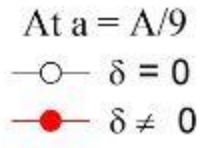
Methodology

- Modified temperature dependent pairing energy coefficient δ(T) is obtained from earlier quantum mechanical fragmentation theory (QMFT)-based model calculations (M. Bansal, R. Kumar, and R. K. Gupta, J. Phys.: Conf. Ser. 321, 012046 (2011)).
- The variation of pairing energy coefficient δ with T obtained from QMFT-based model calculations (solid line) is compared with that used by Davidson et al. in their T-dependent liquid drop model (dotted line) in Fig.
- QMFT suggests a slower fall of pairing energy term with temperature.
- In present study of $^{24,25}Mg^{*}$ CN formed in $^{12,13}C + ^{12}C$ reactions, we used this modified pairing energy term.



Result & discussion





- Fig. 1(a-d) presents fragmentation potential of the decaying nuclei $^{25}Mg^{*}$ and $^{24}Mg^{*}$ with and without the inclusion of pairing energy coefficient (δ).
- The new values of δ for $^{25,24}Mg^{*}$ are 1.808MeV and 1.491MeV, at Temperature T = 4.592Mev and 4.689MeV, respectively.

Fig.1 Comparison of fragmentation profile of favored fragments of (a) $^{25}Mg^{*}$ with Spherical and (b) Deformed configuration (c) $^{24}Mg^{*}$ with Spherical and (d) Deformed configuration at E* ~ 53.9 MeV at critical ℓ value.

Result & discussion

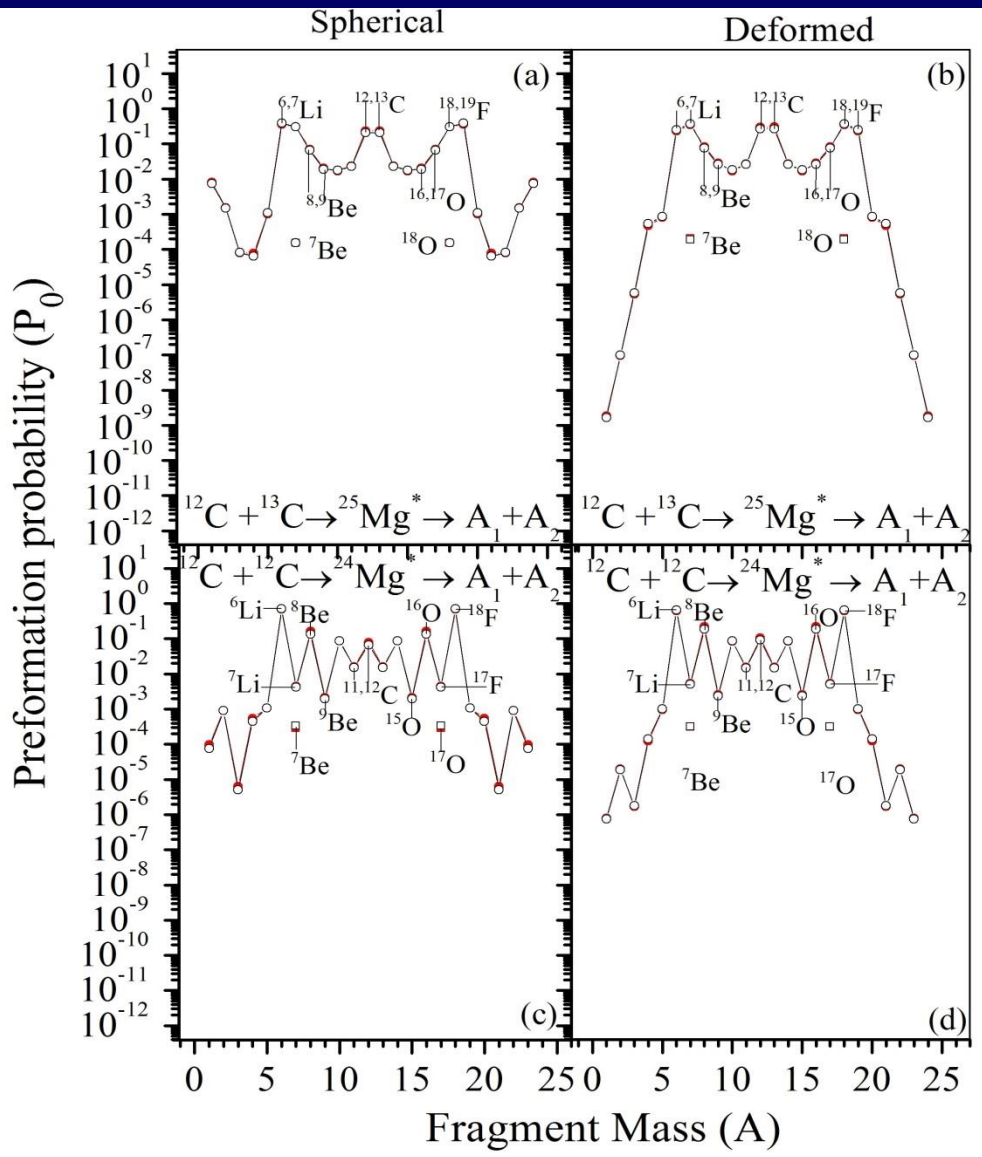


Fig.2 Same as Fig. 1 but for Preformation Probability

At a = A/9

○— δ = 0

●— δ ≠ 0

- There is no major difference in fragmentation potential with both values of δ i.e. with and without inclusion of δ, for spherical and deformed configurations. Hence there is no effect of paring energy coefficient on the fragmentation profile of $^{25}Mg^*$ and $^{24}Mg^*$.
- Fragmentation profile results are further reflected through the preformation probability graph as shown in Fig. 2(a-d). It can be observed that the fragments with α-cluster in exit channel are more preformed.
- As in Fig. 1 inclusion of pairing energy coefficient does not effect the preformation profile.

Result & discussion

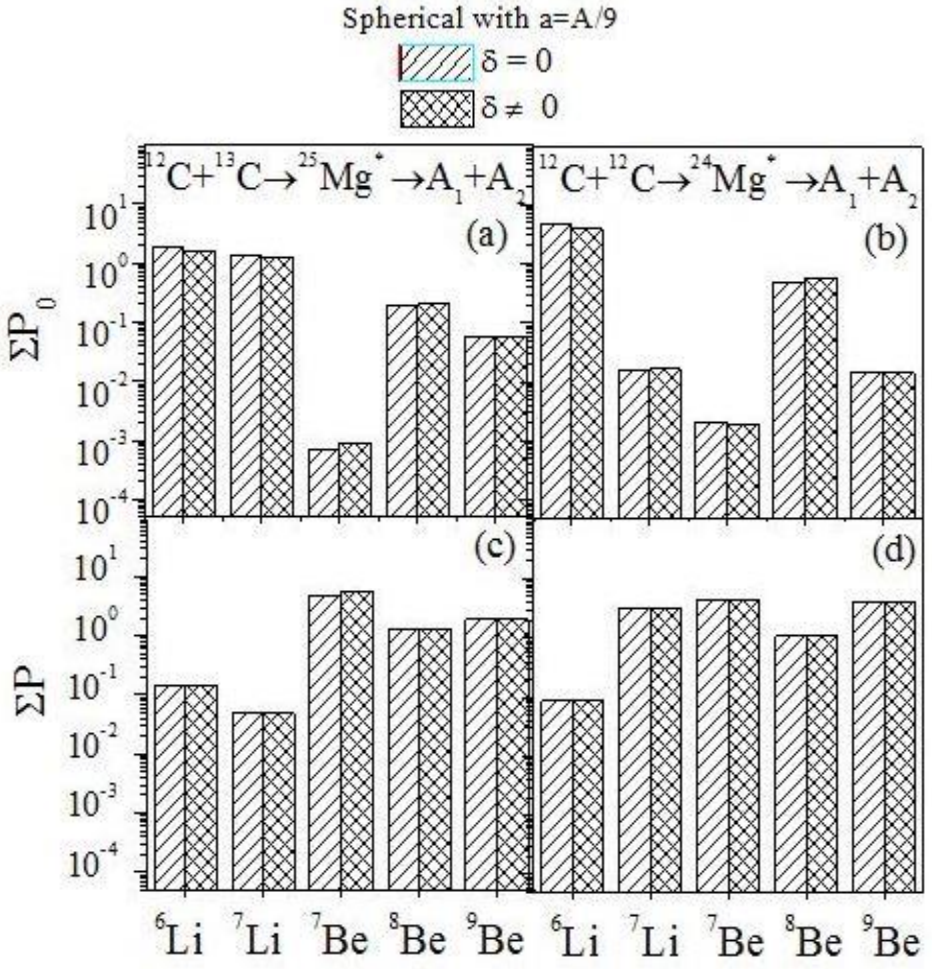


Fig.3 Comparison of ΣP_0 and Σ P of IMFs of the compound nucleus $^{25}Mg^{*}$ and $^{24}Mg^{*}$ with and without inclusion of pairing energy coefficient for spherical configuration.

- Fig. 3(a-b) presents the calculated ℓ-summed up preformation probability (ΣP_0) as a function of fragment mass for spherical consideration of $^{25}Mg^{*}$ and $^{24}Mg^{*}$ CN. Similarly Fig. 3(c-d) presents ℓ-summed up penetrability (ΣP).
- Both with inclusion of paring coefficient in comparison of previous DCM published calculations without inclusion of paring.
- It is clear from Fig. 3(a,b) ΣP_0 of ^{7}Li and ^{9}Be is greater in case of $^{25}Mg^{*}$ in comparison to $^{24}Mg^{*}$ CN, but for other IMFs ^{6}Li, ^{7}Be and ^{8}Be it is more for $^{24}Mg^{*}$ in comparison to $^{25}Mg^{*}$ but opposite trend for ΣP as in Fig. 3(c-d) lead to the cross section ratios.

Result & discussion

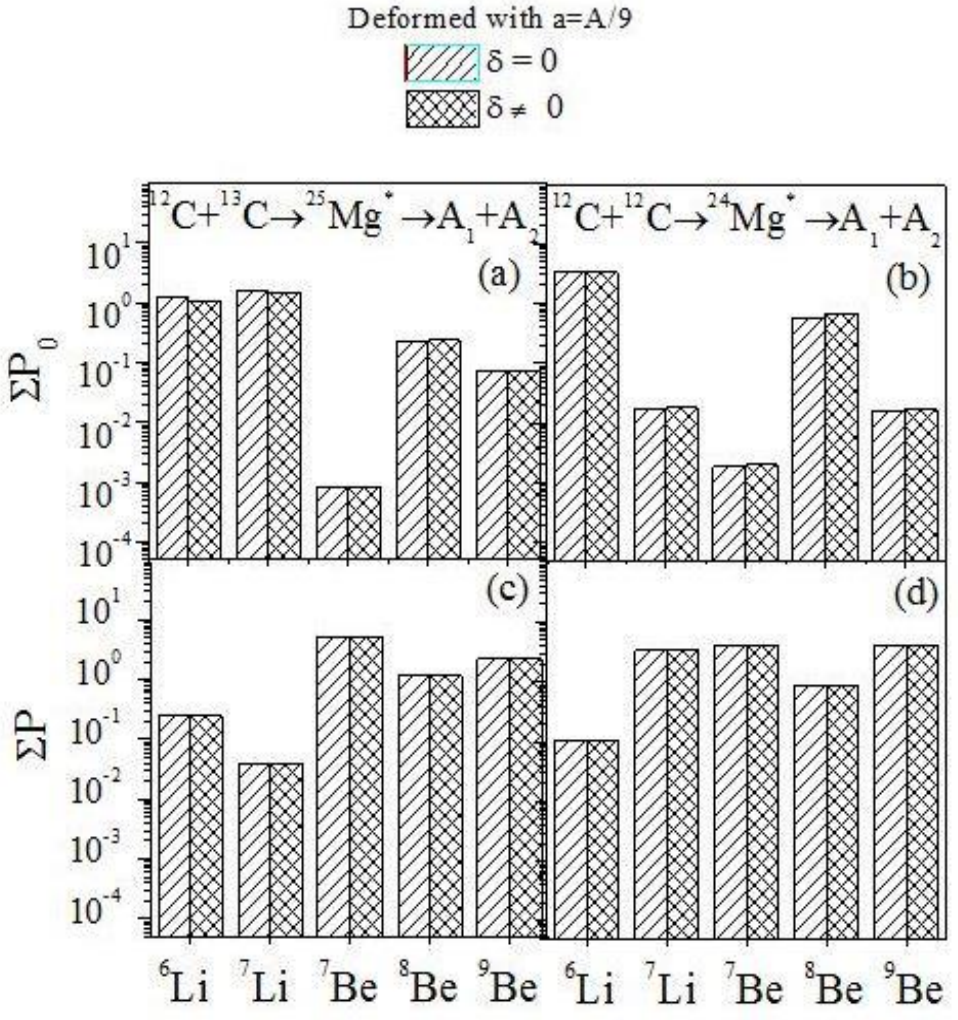


Fig.4 Same as Fig. 3 but for deformed configuration.

- Fig. 4(a-d) is same as Fig. 3(a-b) but for deformed configuration for both ℓ-summed up preformation probability (ΣP_0) and penetrability (ΣP).
- From Fig. 3 and Fig. 4 it is evident there is no effect of paring coefficient on ΣP_0 and ΣP for both the spherical and deformed choice.
- The combine effect of higher values of ΣP_0 and lower values of ΣP for both the spherical and deformed configurations, gives cross section ratio as shown in Fig. 5.

Result & discussion

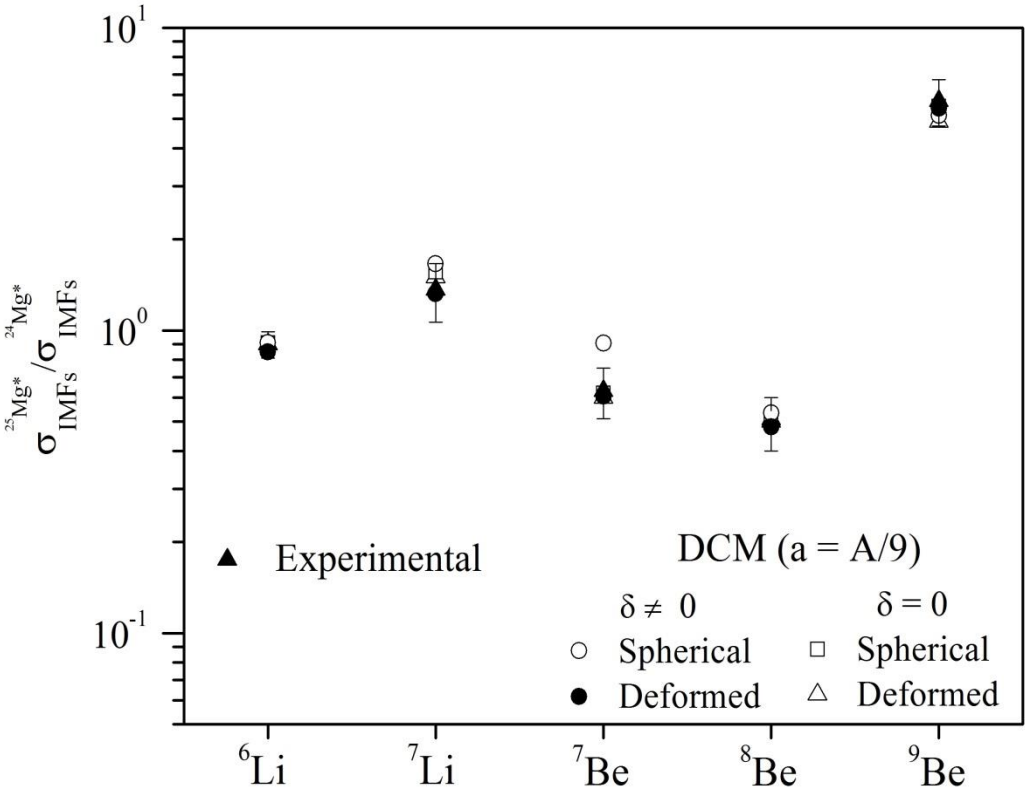


Fig.5 Comparison of cross section ratio of ^{25}Mg* and ^{24}Mg* CN.

- As mentioned in previous slides $\sum P_0$ and $\sum P$ ratio leads to cross section ratios which follows the trend of $\sum P_0$ as presented in Fig. 3,4.
- Also the calculated ratios of cross section of the IMFs (^{6,7}Li and ^{7,8,9}Be) are in fair agreement with the experimental ratios.

- In Fig. 5, the solid triangle represents the experimental data, open and solid circles represent the modified DCM calculations with inclusion of paring energy term, whereas the open square and open triangle depicts the previous DCM calculations with without inclusion of paring energy term.

Summary

- The calculated ratio of $\sum P_0$ of the IMFs shows the trend of ratio of experimental cross sections and are in fair agreement with the experimental data.
- It is found that by including pairing coefficient there is no significant change in fragmentation profile, preformation profile and penetrability and hence the cross section ratios.
- Present calculations have been done by using Davidson's Binding energy, we will further extend this work by using relativistic mean field theory (RMFT) based Binding energies, where we will further investigate these effects on clustering in the exit channels of $^{12,13}C + ^{12}C$ reactions and we will compare it with Davidson's Binding energy based present and previous work.

Thank You!