# Analysis of intrinsic fusion barriers for optimal energy and maximum angular momentum in heavy-ion collisions

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## Introduction

The study of low energy heavy ion fusion reactions is important for planning experiments to synthesize new elements in which knowledge of beam energy is of the utmost importance. The main hindrance to the fusion process is the intrinsic fusion barrier $B^*_{fus}$, which is the difference between a maximum value of the fragmentation potential for forming a compound system between $A_2$=1 and $A_2$=$A_P$ (mass of the projectile) and the potential corresponding to $A_P$. The fragmentation potential depends not only on the internuclear separation and orientations of the colliding nuclei, but also on the incident energy and angular momentum of the compound nucleus formed. So, to find suitable energy, angular momentum, and orientation for the fusion of the colliding nuclei, an analysis of the fragmentation potentials at various incident energy values, angular momentum, and orientation is required. Recently, the barrier analysis has been made to obtain a suitable target-projectile combination for the fusion of the isotopes of Ti and Nd for various combinations of deformation in optimum orientations, but for $\ell$=0 and the ground state [1]. Here, $B^*_{fus}$ have been analyzed for reaction $^{40}$Ar+$^{110}$Pd→ $^{150}$Gd* over an incident energy range 66.26-197.59 MeV, $\ell$-range 0-130 $\hbar$ and considering the colliding spherical nuclei in the touching configuration. The optimal incident energy (energy that corresponds to the zero or the relatively low value of the $B^*_{fus}$) and the maximum value of angular momentum has been obtained for fusion.

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## Methodology

The fragmentation potential for fixed internuclear separation R and mass asymmetry coordinate $\eta = \frac{A_1-A_2}{A_1+A_2}$ is given as

$$V(R,\eta,T,\ell) = \sum_{i=1}^{2} B(Z_i,A_i,T) + V_P(R,T) + V_C(R,T) + V_\ell(R,\ell,T) \quad (1)$$

where the binding energy B($Z_i$,$A_i$,T) is the sum of temperature-dependent liquid drop energy $V_{LDM}$(T) of Davidson *et al.* [2], and the empirical shell corrections $\delta U_i$ of Myers and Swiatecki [3], the temperature-dependence of which is taken from ref. [4]. The nuclear proximity potential $V_P$ is of Blocki *et al.* [5] with T-dependent nuclear radii: $R_i$=(1.28$A_i^{\frac{1}{3}}$-0.76+0.8$A_i^{-\frac{1}{3}}$)(1+0.0007$T^2$). The terms $V_C$ and $V_\ell$ correspond to Coulomb and centrifugal potential, respectively. The temperature (T) of a compound nucleus with mass number A is obtained using relation $E^*_{CN}$=$\left(\frac{A}{9}\right)T^2$-T. The bulk and asymmetry constants of Seeger's mass formula [6] adjusted to reproduce the ground state mass excess of AME2016 and FRDM(2012) is used; for detail, see ref. [7]. Mathematically, the intrinsic fusion barrier is given as $B^*_{fus}(T,\ell) = V^{max}(A_2,T,\ell) - V(A_P,T,\ell)$, where $V^{max}(A_2,T,\ell)$ is the maximum value of fragmentation potential between $A_2$=1 and $A_P$ and V($A_P,T,\ell$) corresponds to the fragmentation potential at $A_2$=$A_P$, see Fig. 1.

## Results and Discussion

Fig. (1) shows that at $E_{cm}$=66.26 MeV $B^*_{fus}(\ell=100)$ > $B^*_{fus}(\ell=0)$, that is a rise of

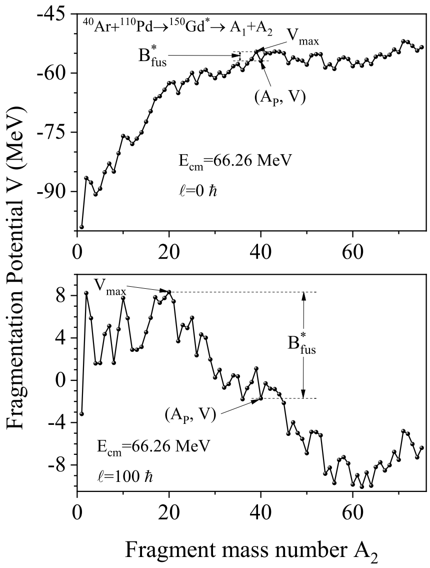


FIG. 1: Fragmentation potential as a function of light fragment mass number $A_2$ at $\ell$=0 (upper panel) and 100 $\hbar$ (lower panel) for the reaction $^{40}$Ar+$^{110}$Pd.

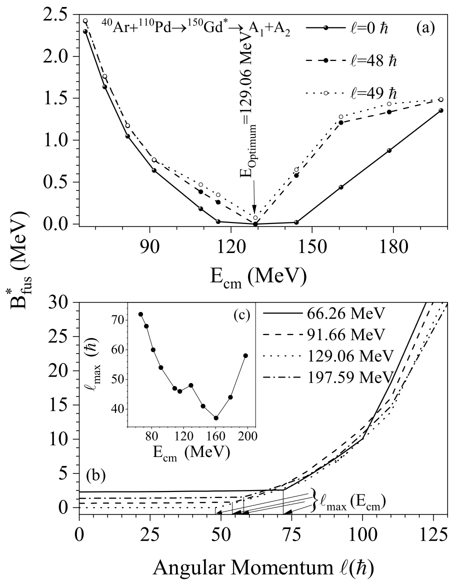


FIG. 2: Intrinsic fusion barrier $B^*_{fus}$ as a function of (a) incident energy, (b) angular momentum and (c) $\ell_{max}$ variation with incident energy.

$B^*_{fus}$ with angular momentum which corresponds to the decrease of fusion probability with the increase of angular momentum.

Fig. 2 (a) shows that at $\ell$=0 the $B^*_{fus}$-value reduces to zero at incident energies of 129.06 MeV and beyond this energy it increases again. At a given energy, the $B^*_{fus}$-value increases with angular momentum and reduces to zero at 129.06 MeV up to 48 $\hbar$. Above the angular momentum of 48 $\hbar$, the $B^*_{fus}$-value is minimal at 129.06 MeV and therefore called as *optimal energy* for the fusion of $^{40}$Ar+$^{110}$Pd. Fig. 2 (b) shows that the $B^*_{fus}$ remains nearly constant up to a certain angular momentum, called $\ell_{max}$, and above $\ell_{max}$ there is a rapid increase in $B^*_{fus}$-values. Thus, we can say that the fusion process is favoured over angular momentum range 0-$\ell_{max}$. The variation of $\ell_{max}$ with $E_{cm}$ shows a decrease of $\ell_{max}$ with $E_{cm}$ up to 160.66 MeV, and beyond 160.66 MeV it again increases. Also, the $\ell_{max}$-value at optimal energy is relatively higher, which means fusion is favoured up to a little higher angular momentum value.

## Conclusion

The intrinsic fusion barrier's energy and angular momentum variation can give us the optimal energy and maximum value of angular momentum for the fusion process.

## References

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