

Non-Coplanar Nuclei in Heavy-Ion Reactions

Sahila Chopra, Hemdeep, Arshdeep Kaur, Raj K. Gupta

Abstract—In recent times, we noticed an interesting and important role of non-coplanar degree-of-freedom ($\Phi \neq 0^0$) in heavy ion reactions. Using the dynamical cluster-decay model (DCM) with Φ degree-of-freedom included, we have studied three compound systems $^{246}\text{Bk}^*$, $^{164}\text{Yb}^*$ and $^{105}\text{Ag}^*$. Here, within the DCM with pocket formula for nuclear proximity potential, we look for the effects of including compact, non-coplanar configurations ($\Phi_c \neq 0^0$) on the non-compound nucleus (nCN) contribution in total fusion cross section σ_{fus} . For $^{246}\text{Bk}^*$, formed in $^{11}\text{B}+^{235}\text{U}$ and $^{14}\text{N}+^{232}\text{Th}$ reaction channels, the DCM with coplanar nuclei ($\Phi_c = 0^0$) shows an nCN contribution for $^{11}\text{B}+^{235}\text{U}$ channel, but none for $^{14}\text{N}+^{232}\text{Th}$ channel, which on including Φ gives both reaction channels as pure compound nucleus decays. In the case of $^{164}\text{Yb}^*$, formed in $^{64}\text{Ni}+^{100}\text{Mo}$, the small nCN effects for $\Phi=0^0$ are reduced to almost zero for $\Phi \neq 0^0$. Interestingly, however, $^{105}\text{Ag}^*$ for $\Phi = 0^0$ shows a small nCN contribution, which gets strongly enhanced for $\Phi \neq 0^0$, such that the characteristic property of P_{CN} presents a change of behaviour, like that of a strongly fissioning superheavy element to a weakly fissioning nucleus; note that $^{105}\text{Ag}^*$ is a weakly fissioning nucleus and P_{surv} behaves like one for a weakly fissioning nucleus for both $\Phi = 0^0$ and $\Phi \neq 0^0$. Apparently, Φ is presenting itself like a good degree-of-freedom in the DCM.

Keywords—Dynamical cluster-decay model, fusion cross sections, non-compound nucleus effects, non-coplanarity.

I. INTRODUCTION

WE have analyzed in this work that non-coplanar degree-of-freedom (Φ) is an important variant in hot fusion reactions. Using the dynamical cluster-decay model (DCM) [1], for case of nuclear proximity pocket formula of Blocki et al. [2], we have studied three compound systems $^{246}\text{Bk}^*$ [3], [4], $^{164}\text{Yb}^*$ [5], [6], and $^{105}\text{Ag}^*$ [7], [8], formed in various different reactions at many incident center-of-mass energies $E_{c.m.}$. In these three nuclear systems, ‘compact’ coplanar configurations ($\Phi_c=0^0$) present best cases of large non-compound-nucleus (nCN) component in the measured fusion cross section σ_{fus} . In case of $^{246}\text{Bk}^*$, formed in $^{11}\text{B}+^{235}\text{U}$ and $^{14}\text{N}+^{232}\text{Th}$ entrance channels, for $\Phi=0^0$, the quasi-fission (qf)-like nCN component is present in fission cross section of $^{11}\text{B}+^{235}\text{U}$ channel, but not in $^{14}\text{N}+^{232}\text{Th}$ channel. Here, the (qf-like) nCN component is defined as the measure of disagreement between the calculated and measured fission cross section, taken as a measure of σ_{fus} . However, with non-coplanar degree-of-freedom included ($\Phi \neq 0^0$), interestingly in $^{11}\text{B}+^{235}\text{U} \rightarrow ^{246}\text{Bk}^*$ reaction, the nCN contribution is reduced to zero at all incident $E_{c.m.}$, with $^{14}\text{N}+^{232}\text{Th}$ reaction channel keeping the same result ($\sigma_{nCN}=0$) for both cases ($\Phi=0^0$ and $\Phi \neq 0^0$). On the other hand, in the other two reactions $^{64}\text{Ni}+^{100}\text{Mo} \rightarrow ^{164}\text{Yb}^*$ and $^{12}\text{C}+^{93}\text{Nb} \rightarrow ^{105}\text{Ag}^*$, the effect of non-coplanarity ($\Phi \neq 0^0$)

on σ_{nCN} is negligibly small (σ_{nCN} decreased to almost zero for $\Phi \neq 0^0$ case) in the first case, but gets strongly enhanced in the second case such that its ($^{105}\text{Ag}^*$) characteristic properties change, rather leads to a consistent picture for $\Phi \neq 0^0$ from an inconsistent one for $\Phi=0^0$.

The defining of compound nucleus (CN) fusion probability P_{CN} and survival probability P_{surv} have proved a helping hand for explaining the importance of non-coplanarity degree-of-freedom [9], [10]. One of the important result of the variation of P_{CN} with CN excitation energy E^* is the classification of various nuclear systems in to (i) $P_{CN}=1$ ($\sigma_{nCN}=0$) for small E^* but decreases as E^* increases, and (ii) P_{CN} increases with increasing E^* at lower E^* and goes to unity at higher E^* . On the other hand, P_{surv} classified compound nuclear system in to these groups, namely, the weakly fissioning nuclei, radioactive nuclei, and the strongly fissioning superheavy nuclei, with magnitudes of P_{surv} , respectively, ~ 1 , $\sim 10^{-6}$ and $\sim 10^{-10}$. For example, $^{105}\text{Ag}^*$ with co-planar degree-of-freedom ($\Phi = 0^0$), shows the behaviour of the variation of P_{CN} with E^* similar to superheavy systems $^{286}\text{Cn}^*$ and $^{292}\text{Fl}^*$, having $P_{CN} \ll 1$ and increasing with E^* , whereas P_{surv} belongs to weakly fissioning group, decreasing with increasing E^* . For P_{CN} , this happens because $^{105}\text{Ag}^*$ is found [7] to contain a large nCN component and the two superheavy systems are also known to decay dominantly via the qf process. However, on including the Φ degree-of-freedom, the nCN cross section for $^{105}\text{Ag}^*$ gets strongly enhanced such that the behavior of P_{CN} as a function of E^* changes from increasing to decreasing and hence belongs to the group of weakly fissioning nuclei, like for P_{surv} as a function of E^* . Thus, as expected, $^{105}\text{Ag}^*$ with non-coplanar degree-of-freedom included ($\Phi \neq 0^0$) is a weakly fissioning nucleus for both P_{CN} and P_{surv} . Similar interesting, though different, results are obtained for CN $^{164}\text{Yb}^*$ and $^{246}\text{Bk}^*$, and further such studies with non-coplanarity included are called for. One such case [9] is the Pt-isotopes ($^{176-196}\text{Pt}^*$) with $\Phi \neq 0^0$.

Section II gives the formulation of the dynamical cluster-decay model used here. Calculations are discussed in Section III, and our conclusion is presented in Section IV.

II. DYNAMICAL CLUSTER-DECAY MODEL (DCM)

The DCM is based on the well known Quantum mechanical fragmentation theory (QMFT) [1] which, in binary fragmentation process, uses collective coordinates of mass (and charge) asymmetries η (and η_Z) [$\eta = (A_1 - A_2)/(A_1 + A_2)$], $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$], and relative separation R , with multipole deformations $\beta_{\lambda i}$ ($\lambda=2,3,4$; $i=1,2$), orientations θ_i and the azimuthal angle Φ between the principal planes of two nuclei. In terms of these coordinates, for ℓ partial waves,

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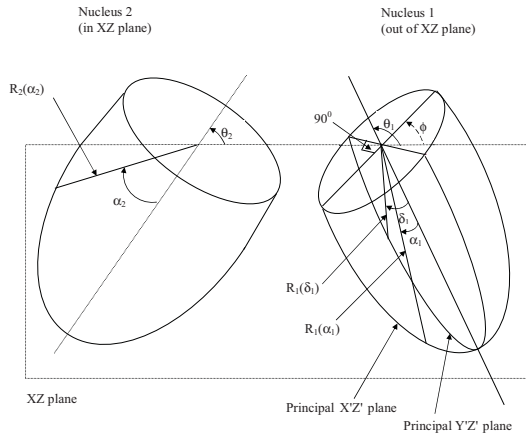


Fig. 1 Two unequal nuclei, oriented at angles θ_1 and θ_2 , with their principal planes $X'Z'$ and XZ making an azimuthal angle Φ . The angle Φ is shown by a dashed line, since it is meant to be an angle coming out of the plane XZ . Nucleus 2 is in XZ plane and for the out-of-plane nucleus 1, another principal plane $Y'Z'$, perpendicular to $X'Z'$, is also shown. The orientation angles θ_i are measured anti-clockwise from the collision Z axis, and the angles α_i (and δ_i) of radius vectors are measured in the clockwise direction from the nuclear symmetry axis

we define the CN-decay/ fragments-formation cross section for each pair of exit/ decay channel as

$$\sigma_{(A_1, A_2)} = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell_{max}} (2\ell + 1) P_0 P; \quad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

where P_0 is fragment preformation probability, referring to η motion at fixed R -value and P , the barrier penetrability, to R motion for each η -value, both dependent on T and ℓ . The reduced mass $\mu = mA_1A_2/(A_1 + A_2)$ with m as the nucleon mass. ℓ_{max} is the maximum angular momentum, defined for light-particles (LPs) evaporation residue cross section $\sigma_{ER} \rightarrow 0$. Then, it follows from (1) that

$$\sigma_{ER} = \sum_{A_2=1}^{4 \text{ or } 5} \sigma_{(A_1, A_2)} \quad \text{or} \quad = \sum_{x=1}^{4 \text{ or } 5} \sigma_{xn}, \quad (2)$$

and

$$\sigma_{ff} = 2 \sum_{A_2=5 \text{ OR } 6}^{A/2} \sigma_{(A_1, A_2)}. \quad (3)$$

The above equation is also applicable to the case where the ff process is measured only up to the, so-called, intermediate mass fragments (IMFs; $5 \leq A_2 \leq 20$, $3 \leq Z_2 \leq 10$) with sum taken up to the maximum measured value of A_2 and without the multiplying factor 2. The same equation (1) is also applicable to the nCN decay process, calculated here as the quasi-fission (qf)-like decay where $P_0=1$. In other words, for σ_{nCN} we use DCM($P_0=1$) for each decay channel. In case the σ_{nCN} were not measured, it can be estimated empirically from the calculated and measured σ_{fus} , as

$$\sigma_{nCN} = \sigma_{fus}^{Expt.} - \sigma_{fus}^{Cal.} \quad (4)$$

where, $\sigma_{fus}^{Cal.} \equiv \sigma_{CN}^{Cal.}$. Thus, using (1) in (2) and (3), the DCM predicts not only the total fusion cross section σ_{fus} , the sum of the cross sections of constituents ER, ff and nCN, but also

the individual cross sections σ_{ER} , σ_{ff} and σ_{nCN} . With the help of these cross sections, we can calculate the CN fusion probability P_{CN} and survival probability P_{surv} .

The CN formation probability P_{CN} is defined as

$$P_{CN} = \frac{\sigma_{CN}}{\sigma_{fusion}} = 1 - \frac{\sigma_{nCN}}{\sigma_{fusion}}, \quad (5)$$

and the CN survival probability P_{surv} , the probability that the fused system will de-excite by emission of neutrons or LPs (equivalently, the ER), rather than fission, as

$$P_{surv} = \frac{\sigma_{ER}}{\sigma_{CN}}, \quad (6)$$

where, $\sigma_{fus} = \sigma_{CN} + \sigma_{nCN}$ and $\sigma_{CN} = \sigma_{ER} + \sigma_{ff}$.

The important parameter of the DCM is the neck-length parameter ΔR , which is directly related to the ‘‘barrier lowering’’, and hence to fusion hindrance phenomenon in heavy-ion reactions. The choice of parameter ΔR , for a best fit to the data, allows us to relate in a simple way the $V(R_a, \ell)$ at $R = R_a$ [defining the first turning point in $V(R)$] to the top of the barrier $V_B(\ell)$ for each ℓ , by defining their difference $\Delta V_B(\ell)$, the effective ‘‘lowering of the barrier’’, as

$$\Delta V_B(\ell) = V(R_a, \ell) - V_B(\ell). \quad (7)$$

Note, ΔV_B for each ℓ is defined as a negative quantity since the actually used barrier is effectively lowered. Thus, the fitting parameter ΔR controls the ‘‘barrier lowering’’ ΔV_B .

To calculate the cross sections for non-coplanar nuclei ($\Phi \neq 0^0$) (see fig. 1), we use the same formalism as for $\Phi = 0^0$ (see, [11]), but by replacing for the out-of-plane nucleus ($i=1$ or 2) the corresponding radius parameter $R_i(\alpha_i)$ with its projected radius parameter $R_i^P(\alpha_i)$ in both the Coulomb and proximity potentials [12]. For Coulomb potential, it enters via $R_i(\alpha_i)$ itself, and for the proximity potential via the definitions of both the mean curvature radius \bar{R} and the shortest distance s_0 , i.e., compact configurations with orientations θ_{ci} and Φ_c [13], [14]. For compact configurations, the interaction radius is smallest and the barrier is highest.

The $R_i^P(\alpha_i)$ is determined by defining, for the out-of-plane nucleus, two principal planes $X'Z'$ and $Y'Z'$, respectively, with radius parameters $R_i(\alpha_i)$ and $R_j(\delta_j)$, such that their projections into the plane (XZ) of the other nucleus are (see Fig. 1)

$$R_i^P(\alpha_i) = R_i(\alpha_i) \cos \Phi \quad i=1 \text{ or } 2, \quad (8)$$

and

$$R_j^P(\delta_j) = R_j(\delta_j) \cos(\Phi - \delta_j) \quad j=i=1 \text{ or } 2. \quad (9)$$

Then, maximizing $R_j(\delta_j)$ in angle δ_j , we get

$$\begin{aligned} R_i^P(\alpha_i) &= R_i^P(\alpha_i = 0^0) + R_i^P(\alpha_i \neq 0^0) \\ &= R_j^P(\delta_j^{max}) + R_i(\alpha_i \neq 0^0) \cos \Phi, \end{aligned} \quad (10)$$

with δ_j^{max} given by the condition (for fixed Φ),

$$\tan(\Phi - \delta_j) = -\frac{R_j'(\delta_j)}{R_j(\delta_j)}. \quad (11)$$

Thus, the Φ -dependence of projected radius vector $R_i^P(\alpha_i)$ is also contained in maximized $R_j^P(\delta_j^{max})$. For further details,

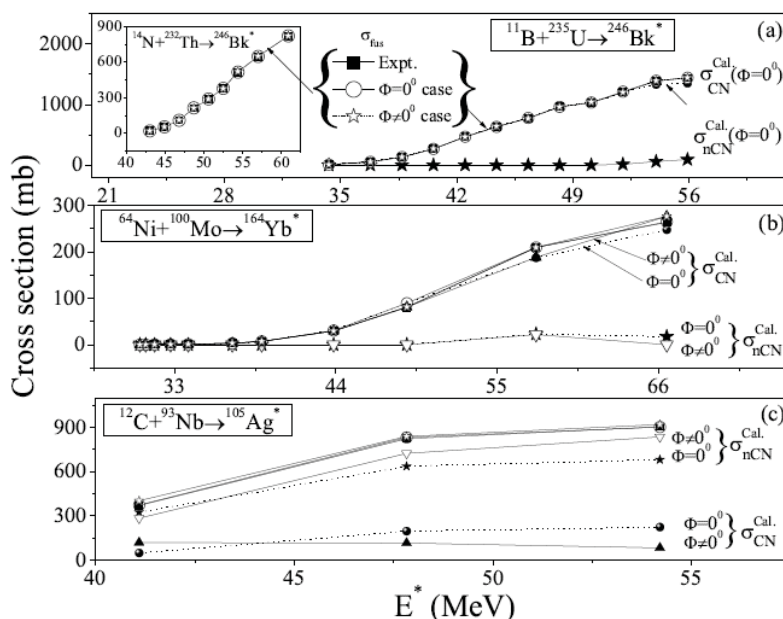


Fig. 2 Comparing the cross sections of three nuclear systems $^{246}\text{Bk}^*$, $^{164}\text{Yb}^*$ and $^{105}\text{Ag}^*$, using DCM with $\Phi_c=0^0$ and $\Phi_c \neq 0^0$, for showing the effect of non-coplanarity on non-compound nucleus (nCN) contribution σ_{nCN} in σ_{fus}

see [12]. Then, for nuclear proximity potential, denoting by V_P^{12} the potential for the nucleus 1 to be out-of-plane, and by V_P^{21} for the nucleus 2 to be out-of-plane, the effective nuclear proximity potential $V_P = \frac{1}{2}[V_P^{12} + V_P^{21}]$.

III. CALCULATIONS AND RESULTS

In this section, we compare our results of using the DCM for three nuclear systems $^{246}\text{Bk}^*$, $^{164}\text{Yb}^*$ and $^{105}\text{Ag}^*$, to see the effect of non-coplanarity degree-of-freedom ($\Phi \neq 0^0$) on nCN contribution in σ_{fus} . The interesting result is that the effect of non-coplanarity is different in different reactions.

In Fig. 2(a), the CN $^{246}\text{Bk}^*$, formed in two incoming reaction channels $^{11}\text{B}+^{235}\text{U}$ and $^{14}\text{N}+^{232}\text{Th}$ at sub-, near- and above-barrier energies [15], [16], is highly fissile and decays totally via fission cross section, taken as the measure of fusion cross section $\sigma_{fus}^{Expt} (= \sigma_{fiss}^{Expt})$. No contribution due to the emission of LPs ($A \leq 4$), IMFs ($5 \leq A \leq 20$) or qf-like nCN processes are explicitly recorded in these experiments. However, in Fig. 2(a), calculations [3], [4] for coplanarity of nuclei ($\Phi=0^0$) show that, in contrast to experiments [15], [16], a non-CN/ qf component is present in the fission cross section of $^{11}\text{B}+^{235}\text{U}$ channel, but not in $^{14}\text{N}+^{232}\text{Th}$ channel. We notice that for $^{11}\text{B}+^{235}\text{U}$ channel, $^{246}\text{Bk}^*$ with $\Phi = 0^0$ has the nCN component at higher three energies, and at other energies it shows a good agreement with the experimental data (compare $\sigma_{CN}^{Cal.}, \Phi = 0^0$ with σ_{fus}^{Expt}). However, $\Phi \neq 0^0$ nullify completely this disagreement between experimental data and calculated results, and both the channels (main figure and inset) show σ_{fus} as pure CN cross section for $\Phi \neq 0^0$.

Fig. 2 (b) shows the case of $^{164}\text{Yb}^*$, where allowing non-coplanarity ($\Phi \neq 0^0$) fits the data nearly exactly, with a strongly reduced nCN contribution. For $\Phi=0^0$ case, the nCN contribution is non-zero at the highest two energies, which for $\Phi \neq 0^0$ reduces to only one of them. Thus, for $^{164}\text{Yb}^*$, the

nCN contribution is reduced almost to zero, and the reaction for $\Phi \neq 0^0$ could be taken as pure CN reaction. The deviations of $\sigma_{fus}^{Cal.}$ from σ_{fus}^{Expt} , with and without Φ , are simply due to large errors in data [17].

Fig. 2 (c) shows the interesting result of non-coplanarity on nCN contribution in the case of $^{105}\text{Ag}^*$. We notice that, for a best fit to data [18], in going from $\Phi = 0^0$ to $\Phi \neq 0^0$, instead of decreasing, the nCN contribution has increased considerably. An important effect of this result is that now the variations of both P_{CN} and P_{surv} support the fact that $^{105}\text{Ag}^*$ belongs to the same group of weakly fissioning nuclei, i.e., both P_{CN} and P_{surv} decrease with increasing E^* for $\Phi \neq 0^0$.

Another important result follows from the neck-length parameter ΔR value, in going from $\Phi = 0^0$ to $\Phi \neq 0^0$. We found a similar trend of ΔR variation in $^{164}\text{Yb}^*$ and $^{105}\text{Ag}^*$, but a reverse one in the case of $^{246}\text{Bk}^*$. For $^{164}\text{Yb}^*$ only fusion-evaporation residue (ER) cross section is measured at extreme sub-barrier energies, and in $^{105}\text{Ag}^*$ we have the measured data for evaporation residues ER and the IMFs. In these two cases, we have found that ΔR is larger in case of $\Phi \neq 0^0$ as compared to $\Phi = 0^0$ case. Alternatively, in $^{246}\text{Bk}^*$, experimentally only fission data is available, and according to DCM its ΔR is small in the case of $\Phi \neq 0^0$ as compared to the case of $\Phi = 0^0$ [4].

IV. CONCLUSION

Concluding, non-coplanarity is an important, independent degree-of-freedom, which must be included in every study of heavy ion reaction.

ACKNOWLEDGEMENT

Work supported by the Women Scientist Scheme (WOS-A), Grant No. SR/WOS-A/PS-52/2013(G), and a Research Project No. SR/S2/HEP-12/2012, of Ministry of Science &

Technology, Department of Science & Technology (DST), Government of India.

REFERENCES

- [1] R. K. Gupta, in *Clusters in Nuclei*, Lecture Notes in Physics 818, edited by C. Beck, Vol.I, (Springer Verlag, Berlin, 2010), pp. 223-265; and earlier references there in it.
- [2] J. Blocki *et al.*, *Proximity Forces*, Ann. Phys. (N.Y.) 105, 427 (1977).
- [3] R. K. Gupta and M. Bansal, *Heavy Ion Reactions Studied on Wong and Dynamical Cluster-Decay Models Using Proximity Potential for Non-Coplanar Nuclei*, Int. Rev. Phys. (IREPHY) 5, 74 (2011).
- [4] M. Bansal, *Study of Fusion Reactions Using Deformed and Oriented Nuclei*, Ph.D. thesis, Panjab University, Chandigarh, 2012, Chapters 5 and 6 (Unpublished).
- [5] S. K. Arun, R. Kumar, and R. K. Gupta, *Fusion-evaporation cross-sections for the $^{64}\text{Ni}+^{100}\text{Mo}$ reaction using the dynamical cluster-decay model*, J. Phys. G: Nucl. Part. Phys. 36, 085105 (2009).
- [6] M. Bansal *et al.*, *Dynamical cluster-decay model using various formulations of a proximity potential for compact non-coplanar nuclei: Application to the $^{64}\text{Ni}+^{100}\text{Mo}$ reaction*, Phys. Rev. C 86, 034604 (2012).
- [7] S. Chopra *et al.*, *One neutron and noncompound-nucleus decay contributions in the $^{12}\text{C}+^{93}\text{Nb}$ reaction at energies near and below the fusion barrier*, Phys. Rev. C 88, 014615 (2013).
- [8] S. Chopra *et al.*, *Non-coplanar compact configurations of nuclei and non-compound-nucleus contribution in the fusion cross section of the $^{12}\text{C}+^{93}\text{Nb}$* , Phys. Rev. C 93, 024603 (2016).
- [9] A. Kaur *et al.*, *Compound nucleus formation probability P_{CN} determined within the dynamical cluster-decay model for various hot fusion reactions*, Phys. Rev. C 90, 024619 (2014).
- [10] S. Chopra *et al.*, *Determination of the compound nucleus survival probability P_{surv} for various hot fusion reactions based on the dynamical cluster-decay model*, Phys. Rev. C 91, 034613 (2015).
- [11] R. K. Gupta *et al.*, *Generalized proximity potential for deformed, oriented nuclei*, Phys. Rev. C 70, 034608 (2004).
- [12] M. Manhas and R. K. Gupta, *Proximity potential for deformed, oriented nuclei: "Gentle" fusion and "hugging" fusion*, Phys. Rev. C 72, 024606 (2005).
- [13] R. K. Gupta *et al.*, *Optimum orientations of deformed nuclei for cold synthesis of superheavy elements and the role of higher multipole deformations*, J. Phys. G: Nucl. Part. Phys. 31, 631 (2005).
- [14] R. K. Gupta *et al.*, *Compactness of the ^{48}Ca induced hot fusion reactions and the magnitudes of quadrupole and hexadecapole deformations*, Phys. Rev. C 73, 054307 (2006).
- [15] B. R. Behera *et al.*, *Entrance-channel effect in fusion fragment anisotropies from $^{11}\text{B}+^{235}\text{U}$ and $^{14}\text{N}+^{232}\text{Th}$ systems*, Phys. Rev. C 64, 041602(R) (2001).
- [16] B. R. Behera *et al.*, *Fission fragments angular distributions for the systems $^{14}\text{N}+^{232}\text{Th}$ and $^{11}\text{B}+^{235}\text{U}$ at near and sub-barrier energies*, Phys. Rev. C 69, 064603 (2004).
- [17] C. L. Jiang *et al.*, *Hindrance of heavy-ion fusion at extreme sub-barrier energies in open-shell colliding systems*, Phys. Rev. C 71, 044613 (2005).
- [18] T. Ahmad *et al.*, *Reaction Mechanisms in $^{12}\text{C}+^{93}\text{Nb}$ system: Excitation functions and recoil range distributions below 7 MeV/u*, Int. J. Mod Phys. E 20, 645 (2011).



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