# Fusion of neutron/proton-rich colliding nuclei using different models

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## Introduction

Considerable experimental and theoretical efforts have been devoted in recent time to the understanding of fusion mechanism of neutron /proton-rich colliding nuclei [1, 2]. Investigations of such nuclei have important implications in the production of super heavy elements. Interesting systematic features have been observed and a large number of studies have been undertaken for their interpretation through various microscopic/macroscopic models [1, 2]. Most of these models are based on the proximity concept [3]. Several modification and parametrization of such models have been suggested from time to time [4] by including different degrees of freedom such as, neutron skin, isospin etc. All experimentally studied nuclei in fusion studies contain $N/Z \leq 1.6$. It is therefore necessary to test the validity of these models for nuclei far away from the line of stability in different mass region and further to understand its effect in fusion dynamics.

## The Model

The present study is carried out within the framework of Proximity concept. In this framework, nuclear part of the interaction potential is a product of geometrical factor and universal function. According to original proximity potential [3], nuclear part of the interaction potential $V_N(r)$ can be written as:

$$V_N(r) = 4\pi \bar{R} \gamma \phi(s). \qquad (1)$$

Here $\bar{R}$, $\gamma$ and $\varphi(s)$ represents reduced radius, surface energy coefficient and universal function respectively. Also the nuclear potential strength has a dependence on the relative neutron excess of the projectile and target through $\gamma$ and a mass dependence through the reduced radius factor. Similarly, several modifications/parametrizations over the original proximity potential are available in the literature [4]. These modifycations or refinements included better form of $\gamma$, $\varphi$ (s) and radius, obtained by adding different terms like, neutron skin, isospin and recent available theoretical as well as experimental knowledge. In total, eight such modals are taken into consideration namely; Bass 80, Ngô 80, AW 95, Denisov N, Prox 77, Prox 88, Prox 00, and Prox 00-N. The detail of these models is presented in Ref. [4]. Once nuclear potential is obtained the total interaction potential is calculated by adding Coulomb potential ($=Z_1Z_2e^2/r$) to Eq. (1).

## Results and Discussion

We have studied the collision of three different series namely; Ne-Ne (with $A_S$ (= N/Z-1) = -0.4-1.0; where N and Z are total neutrons and protons content) , Ca-Ca ($A_S$ = -0.5 -1.0), Zr-Zr ($A_S$ = -0.25-1.0). These series are under taken, to test all above variety of models in a much wider mass region. Here we studied the effect of addition and removal of neutrons on the N=Z nuclei. In total, 150 different combinations of the above mentioned series are considered.

We have calculated the barrier height $V_B$ and its position $R_B$ using different models. It is observed that for neutron-rich nuclei, $V_B$ reduces and $R_B$ shifted outwards, whereas reverse happen for proton-rich nuclei. Further, it is noticed that diffuseness of the barrier as well as depth of the pocket is also changed with neutron/proton content or mass number. This is mainly due to reduced radius factor. All above mentioned models follow almost similar pattern [2]. We also noticed that the shape of the potential also varies from model to model. Since fusion occurs at the surface of two interacting nuclei, therefore interior part of the potential shape is not much important. For a more meaningful discussion we define following normalized variation in barrier positions and similarly heights over N=Z case as:

$$\Delta R_B \% = \frac{R_B - R_B{}^0}{R_B{}^0} \times 100. \qquad (2)$$

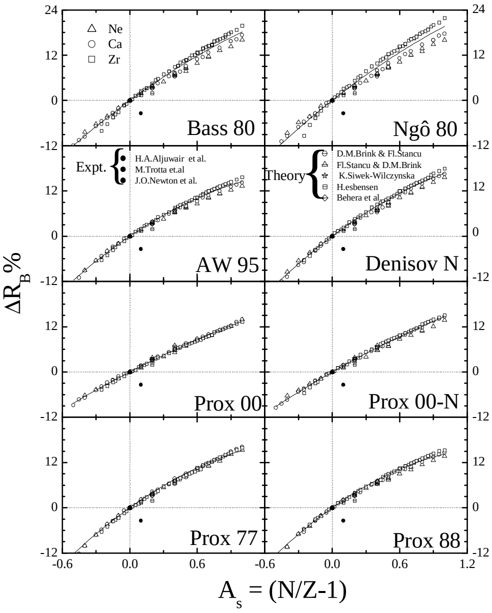

**Fig. 1** The normalized barrier position $\Delta R_B\%$ as a function of $A_S$ using different models (Preliminary results).

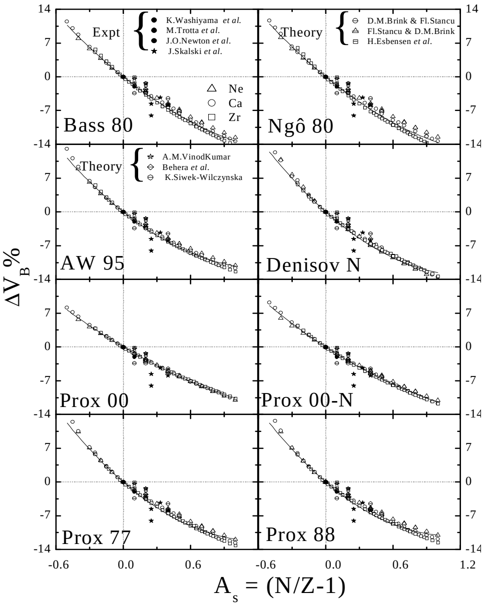

**Fig. 2** Same as Fig. 1 but for $\Delta V_B\%$ (Preliminary results).

Where $R_B^0$ = $R_B$ (N=Z) is barrier position for N=Z case. In Fig. 1, we plotted $\Delta R_B\%$ as a function of $A_S$ using eight different models. Similarly, the corresponding barrier heights are displyed in Fig. 2. It is observed that all models follow a single second order non-linear parametrization between $\Delta R_B\%$ and $\Delta V_B\%$ with $A_S$ for both neutron/proton-rich nuclei as [2];

$$\Delta R_B\% = aA_S{}^2 + bA_S. \qquad (3)$$

Here a, and b are constants vary from -2 to -7.03 and 15.43 to 23.62 respectively for all models. Similarly for $\Delta V_B\%$, its values varies from 3.15 to 8.94 and -13.76 to -20.75 respectively. From Fig. 1, it is observed that Prox 00 and Prox 77 do not show mass dependence, whereas other model shows little effects at the extreme ends. On the other hand, in Fig. 2, we noticed that Ngô 80 and Bass 80 again show large scattering from central line for very neutron rich nuclei, whereas other models follow the central line. We also display in Figs. 1 and 2, the available results of other theoretical models as well as experimental measurements [2]. It is clear from the figures that our results are in close agreement with these results except some experimental uncertainties. Finally, we conclude that fusion barrier position increases and height decreases both in second order non-linear fashion with the increase of N/Z ratio of the compound system resulting in a linear dependence for fusion probabilities [2]. More experiments are needed to verify our predictions.

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## References

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