Analytical parametrization of fusion barriers using experimental data as guideline

Ishwar Dutt* and Tapas Sharma
Department of Applied Sciences, Chitkara University, Himachal Pradesh - 174103, INDIA

Introduction

In recent years, the study of fusion barriers in heavy-ion fusion reactions has attracted a lot of attention because it is quite useful for the production of superheavy elements and cluster-decay studies [1, 2]. Furthermore, it is closely related with nucleus-nucleus interaction and hence give valuable information about the nuclear structure effects. Therefore, a systematic study of fusion barrier is of great importance to check the various theoretical nucleus-nucleus interaction potential and to explore the global features of fusion barriers.

As it is clear from the literature, no experiment measures the fusion barrier directly, in all experiments, one can measure only the fusion excitation functions [1]. As a result, to extract the barrier parameters one needs some reliable theoretical approach. At the same time, large number of attempts have also been made to derive a theoretical formula to directly calculate the fusion barriers. The simplest technique used in the literature to derive these formulas is direct parametrization technique [2]. In this technique, one first calculates the fusion barrier heights and positions using some standard theoretical approach and then tries to parametrized the final outcome in terms of some known physical quantities like charges, masses, and isospin of the colliding nuclei. Recently, on the same guidelines pocket formulas are also presented to calculate the fusion barriers using well known proximity type potentials [1, 2].

As we know large amount of experimental data is available on the fusion barriers and cross sections in the last three decades [1, 2]. It is therefore necessary to parametrized these experimental values using direct parametrization technique and derive a new unified formulas to calculate the fusion barrier height and positions. This will be certainly helpful to directly calculate the fusion barrier heights and positions of any colliding partners.

Methodology

For the present analysis, all kind of the reactions involving symmetric ($N = Z$) as well as asymmetric ($N \neq Z$) nuclei are considered. In all, 400 reactions covering almost whole of the periodic table are taken into account. The lightest reaction considered here is of ^{6}Li + ^{9}Be, whereas the heaviest one is of ^{48}Ca + ^{248}Cm.

As a first step, we collected all the experimentally studied fusion barrier positions [1]. Once we have experimental data on fusion barrier positions, a search was made for their parametrization. Since it is evident that fusion barrier positions depend on the size of the colliding systems, the best way is to parametrize them in terms of the radius dependence *i.e.* in terms of $A^{1/3}$.

Results and Discussion

In figure 1, we plotted the experimental fusion barrier positions R_B^{expt} (fm) verses $\left(A_1^{1/3} + A_2^{1/3}\right)$. It is clear from the figure that all data points lies on the straight-line parametrization

$$R_B^{\text{anal}} = \alpha \pm 1.0 + \beta \left(A_1^{1/3} + A_2^{1/3}\right), \qquad (1)$$

where α and β are constants having values 3.26 and 0.95, respectively.

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*Electronic address: `ishwar.dutt@chitkarauniversity.edu.in`

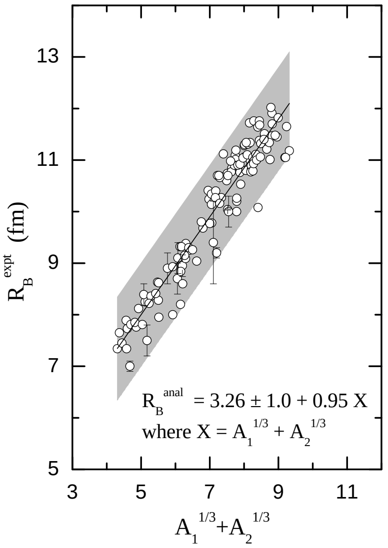

FIG. 1: The variation of experimental fusion barrier positions R_B^{expt} (fm) verses $A_1^{1/3} + A_2^{1/3}$. The solid line shows the straight-line least-squares fit over the data points. The shaded area represents the region within which our analytical expression (Eq. (1)) reproduce experimental data.

In figure 2, we plotted the experimental fusion barrier heights V_B^{expt} (MeV) verses $\frac{Z_1 Z_2 1.44}{R_B^{\mathrm{anal}}}(1 - \frac{1}{R_B^{\mathrm{anal}}})$. From the figure, it is clear that all data points lies on the parametrization

$$V_B^{\mathrm{anal}} = \gamma[\frac{Z_1 Z_2 1.44}{R_B^{\mathrm{anal}}}(1 - \frac{1}{R_B^{\mathrm{anal}}})], \qquad (2)$$

where γ is a constant having value 1.004. Here, the first part is the Coulomb contribution whereas the second part is the reduction due to nuclear potential. Equations (1) and (2) are the analytical expressions to directly calculate the fusion barriers of any colliding nuclei [3]. This shows that our formulas (i.e. Equations (1) and 2)) nicely reproduce the experimental values [3]. The utility of such direct parametrization is that one can use these pocket formulas to find out the fusion barrier positions and heights instantaneously. In addition, it also provides a valuable guideline to design new theories and experiments.

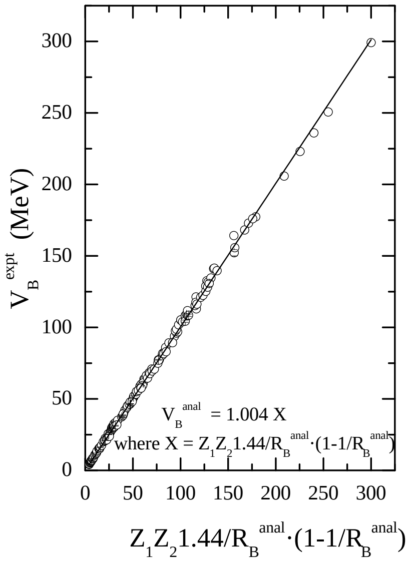

FIG. 2: The variation of experimental fusion barrier heights V_B^{expt} (MeV) verses $\frac{Z_1 Z_2 1.44}{R_B^{\mathrm{anal}}}(1 - \frac{1}{R_B^{\mathrm{anal}}})$. The solid line shows the straight-line least-squares fit over the data points.

Further, we shall extend our work to study the cross sections of different colliding nuclei using these parametrized expressions [3].

References

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