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Parametrization of fusion barriers based on empirical data

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Abstract

Using the empirical/experimental fusion barrier heights and positions, we perform a systematic study for large number of reactions having projectile/target masses $6 \leq A \leq 238$ and present new parameterized form for fusion barrier heights and positions. A comparison with other well known parameterized forms is also made.

Keywords: Fusion barrier; Octupole deformation; Parametrization

1. Introduction

Fusion barriers and systematics is one of the hot topics in low energy nuclear physics. Almost all studies on fusion barriers involving system size dependence end in giving a parameterized form in terms of charges/masses of colliding nuclei [1–6]. Recent years have seen tremendous efforts in this direction using variety of theoretical models, based on the proximity concept [1, 7,8] and others [2]. At the same time, experimental data involving variety of reactions having isotopes, isotones, isobars, symmetric, asymmetric as well as spherical and deformed nuclei are also available. A careful analysis of the previous attempts on fusion barriers and subsequently, parametrization reveals that all models can reproduce experimental/empirical trends on the average [1–6,9,10]. The ultimate aim of these parametrizations is to give homogeneous expressions

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for the fusion barrier parameters, which can be employed for the whole mass range. These expressions act as guidelines in the estimation of fusion cross-section measurements and facilitate the designing of new experiments. None of the parameterized forms, however, could reproduce data precisely. One can see a significant deviation around the mean values (e.g. for fusion positions). Therefore, rather than working within a theoretical model/potential, immediate need is to parameterize the experimental/empirical barriers directly. There are many attempts where parametrizations based on the empirical data [1,9,11] have been used in experimental studies for comparison; and conclusions were drawn on the basis of agreement between the values extracted from the data and the corresponding values from the systematics. In all the cases, where disagreement was observed, the reasons for the same were found to be detection efficiency, insufficient energy range, partial missing of yields of some channels etc. in the experimental setup. Thus, systematics ensures the accuracy of the experimental techniques. The systematics on empirical data due to Vaz et al. [1] has been used for more than three decades in various experimental studies [12]. Another systematic study based on the empirical data by Kovar et al. [9] has been used widely in many experimental studies [13] for comparing the values extracted from the data with systematics results. Motivated by these studies, we aim to parameterize the experimental/empirical barriers directly and to analyze how various factors such as isotopic/isobaric/isotonic content as well as symmetric/asymmetric nature and shape of the colliding nuclei affect the barrier parametrization. We intend to address these questions in the present work. A careful survey of the literature was done to get the empirical data (in terms of fusion barrier heights and positions) and more than 200 reactions [1,9,12–20] involving various above mentioned combinations were identified. Our present analysis has projectiles/targets with masses between 6 and 238. These reactions were then divided into various sub-groups based on the isotopic, isotonic, isobaric content as well as the fixed projectiles and targets.

2. Results and discussion

In Fig. 1, we display the scaled barrier height V_B' $(= V_B/Z_pZ_t)$ as a function of $(A_p^{1/3} + A_t^{1/3})$; p and t signifies projectile and target, respectively. In Fig. 1(a), we display scaled barrier heights for all experimental points. We see that there is a significant scattering around the mean values which is represented by the grey shaded area. In order to understand this scattering, we now constraint the selection of the data to the above mentioned various categories. It is well known that the deformation as well as orientation of the colliding nuclei play a significant role in the complete fusion. Therefore, in Fig. 1(b), we display the barrier heights for spherical colliding nuclei only. It is interesting to note that the barrier heights of all spherical colliding nuclei lie on the parameterized line. In another words, one can predict barrier heights for spherical colliding nuclei accurately.

As a next step, we display in (c), (d), (e), (f), (g) and (h) parts of the figure only those reactions that belong, respectively, to isotopic, isotonic, isobaric, fixed projectile and target (where target (projectile) is varied only) and total fixed mass. One see that constraining reaction series to a particular category does not help in reducing the scattering around the mean curve.

In Fig. 2, we parameterize empirical barrier heights V_B for more than 200 reactions as a function of $\frac{Z_pZ_t}{A_p^{1/3}+A_t^{1/3}}$. This kind of parametrization is also done in Ref. [6]. Our parameterized form reads as

$$V_B^{Par} = -1.01 + 0.93 \times \frac{Z_pZ_t}{A_p^{1/3} + A_t^{1/3}} + \left(4.53 \times 10^{-4}\right) \times \left(\frac{Z_pZ_t}{A_p^{1/3} + A_t^{1/3}}\right)^2. \quad (1)$$