The study of heavy-ion fusion probabilities using different parametrized pocket formulae

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Introduction

In the recent time, the study of fusion cross sections at energies near and below barrier is of central interest [1–3]. Further, it is boosted with the availability of new neutron-rich heavy-ion beams. The above study is also helpful in the synthesis of super heavy elements and in understanding many structural effects. The precise and exact knowledge of fusion barrier is very important in better understanding of the above stated phenomenon.

The experimental (or empirical) fusion barriers are extracted from experimental fusion cross section using some well known theoretical model as a guideline. Theoretically, one can calculate fusion barriers in two different ways. Firstly, one can calculate it from the total ion-ion interaction potential. Secondly, a direct parametrized pocket formulae can be used to calculate barrier parameters. The second method is more useful because it involve direct parametrization technique. According to that, the fusion barriers can be parametrized in terms of basic physical quantities like charge number, mass number and isospin of the colliding partners.

Recently, twelve such parametrized pocket formulae are studies and compared with available experimental data on fusion barriers [1]. Our detailed investigation showed that different parametrized pocket formulae reproduce the experimental fusion barrier heights and positions within ±10% and ±20% respectively [1]. At the same time, the parametrized relations based on Bass 1980, Winther 1995, Prox 1988, and Royer 2001 are very close to experimental data [1]. The outcomes of these pocket formulae on fusion probabilities is still not clear. In this paper, we focus on fusion probabilities using the above four parametrized pocket formulae.

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Methodology

The fusion barriers can be calculated from ion-ion interaction potential using conditions:

$$\frac{dV_T(r)}{dr}|_{r=R_B} = 0; \quad \text{and} \quad \frac{d^2V_T(r)}{dr^2}|_{r=R_B} \leq 0. \tag{1}$$

Here barrier heights and positions are marked respectively as V_B and R_B. Once fusion barriers are calculated, the outcome are further parametrized in terms of simple quantities like charges Z_1, Z_2 and/or masses A_1, A_2 of the colliding nuclei. Several authors parametrized their outcomes in this way [1].

Recently, different proximity potentials are parametrized in this fashion, where fusion barrier height is of from [1]

$$V_B^{\text{Prox}} = \delta\left[\frac{1.44Z_1Z_2}{R_B}\left(1 - \frac{0.75}{R_B}\right)\right]. \tag{2}$$

Here δ is a constant varies from potential to potential. The fusion barrier positions are parametrized as

$$R_B^{\text{Par}} = s_B^{\text{par}} + C_1 + C_2. \tag{3}$$

Where s_B^{par} was of form

$$s_B^{\text{Par}} = \alpha\ exp\left[-\beta\ \left(\frac{Z_1Z_2}{A'} - 2\right)^{1/4}\right], \tag{4}$$

and constants α and β varies from one potentials to other. Here $A' = \left(A_1^{1/3} + A_2^{1/3}\right)$. Also, C_1 and C_2 are half density radii calculated using different forms suggested by authors in Refs. [1, 2]. Depending on the values of these constants we labeled different parametrized pocket formulae as Bass 1980, Prox 1988 and Winther 1995 [1].

Royer *et al.* [4] also obtain a quite complex parametrized pocket formulae to calculate fusion barrier heights and positions as

$$V_B^{\rm Par} = -19.38 + \left[\frac{2.1388\ Z_1Z_2+}{(A')}\times \frac{59.427\,(A') - 27.07\ \ln\left(\frac{Z_1Z_2}{A'}\right)}{(2.97 - 0.12\ \ln\left(Z_1Z_2\right))}\right], \quad (5)$$

and

$$R_B^{\rm Par} = A'\left[1.908 - 0.0857\ \ln\left(Z_1Z_2\right) + \frac{3.94}{Z_1Z_2}\right]. \quad (6)$$

This parametrization is labeled as Royer 2001. Royer *et al.* proposed the above pocket formula from a fitting procedure on GLDM data on 170 fusion reactions, where rms deviations were respectively 0.15 MeV and 0.08 fm [4]. The detail of above all parametrized pocket formulae is given in Ref. [1].

Results and Discussion

As a first step, fusion barriers are calculated for more than 400 reactions using twelve different parametrized pocket formulae. The ourcome of fusion barriers are presented in Ref. [1]. Secondly, fusion probabilities are calculated for few reactions using sharp cut-off model as

$$\sigma_{\rm fus} = \pi R_B^2\left(1 - \frac{V_B}{E_{\rm cm}}\right). \quad (7)$$

In figure 1, we plotted the fusion cross-sections $\sigma_{\rm fus}$ (mb) as a function of center-of-mass energy $E_{\rm c.m.}$. The above variation is studies with reactions ^{26}Mg + ^{30}Si, ^{28}Si + ^{28}Si, ^{16}O + ^{46}Ti, ^{12}C + ^{92}Zr, ^{40}Ca + ^{58}Ni and ^{16}O + ^{144}Sm, respectively. The experimental values are taken from Ref. [3]. It is clear from figure that all parametrized pocket formulae are in good agreement with fusion cross section at above barrier energies. The direct parametrization does not account for the sub barrier fusion probabilities as the information about the ion-ion potential is missing.

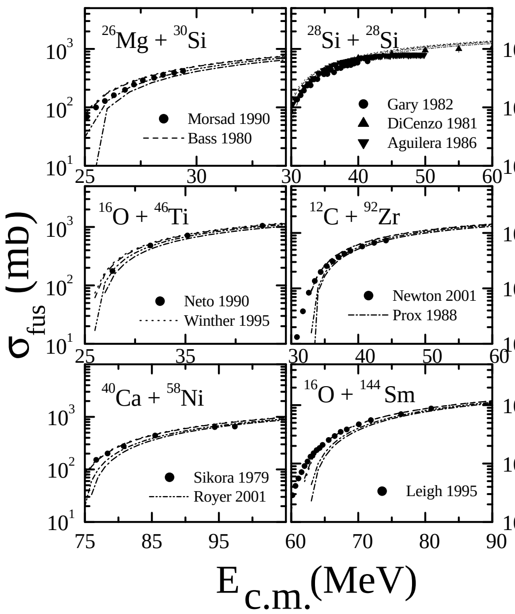

FIG. 1: The fusion cross-sections $\sigma_{\rm fus}$ (mb) as a function of center-of-mass energy $E_{\rm c.m.}$. For the clarity, only four best parametrized pocket formulae are displayed. The experimental values are taken from Ref. [3].

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