Determination of reaction cross sections at intermediate beam energies for normal and exotic nuclei

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The accurate knowledge of the total nuclear reaction cross section (σ_r) in ion-ion collision is essential for extracting nucleon density distributions, nuclear sizes of normal and exotic nuclei and also in other diverse research areas like radiobiology, space sciences etc. Theoretically, there exists two different approaches namely high energy microscopic Glauber theory and the other based on fitting of experimental data and then extrapolation of the fitted curve. The second approach being handier has been employed more often. But in this approach, there is uncertainty associated with the determination of interaction radius ($R_{\rm int}$) , which is an important ingredient cannot be determined by any fundamental principle. As a result such an approach does not give accurate predictions via extrapolation. Very recently, a parameterization scheme for determining the safe lower limit of impact parameter ($b_{\min}$) has been suggested [1]. This $b_{\min}$ may be used in place of $R_{\rm int}$ in the commonly used formula of KOX [2] at intermediate energies and of BCV [3] at relativistic energies for the calculation of total reaction cross sections. In the present study, we have taken Coulomb barrier corrected geometrical formula of KOX as our base formula which is given by

$$\sigma_r = \pi R_{\rm int}^2 \left[1 - \frac{B}{E_{cm}}\right]$$

where $B = \dfrac{Z_p Z_t e^2}{1.3\,(A_p^{1/3} + A_t^{1/3})}$ is the Coulomb barrier with $Z_p(Z_t)$ and $A_p(A_t)$ as the projectile (target) atomic and mass numbers respectively. The E_{cm} is the kinetic energy of the projectile in the center of mass system. After replacing $R_{\rm int}$ by $b_{\min}$ and then by fitting experimental σ_r data at intermediate beam energies ranging from 30-1000 MeV/nucleon for $^{12}C + ^{12}C$ system [2, 4, 5], which has widely been used for validating any new microscopic theory and/or new parameterization scheme, through χ^2 minimization method we have obtained the following expression

$$\sigma_r = \pi\,(b_{\min})^2 \left[1 - \frac{B}{E_{cm}}\right] 0.53494 \left[1 + \frac{0.82587}{1 + \exp((\gamma - 1.014)/0.02077)}\right]$$

with γ as the Lorentz factor. Further, in order to take into account the proton neutron asymmetry in the projectile and the target, this expression is multiplied by an additional asymmetry factor F_{asym} so that it reads

$$\sigma_r = \pi\,(b_{\min})^2 \left[1 - \frac{B}{E_{cm}}\right] 0.53494 \left[1 + \frac{0.82587}{1 + \exp((\gamma - 1.014)/0.02077)}\right] F_{asym} \qquad (1)$$

where

$$F_{asym} = \frac{(A_p^{1/3} + A_t^{1/3})^2}{(A_p^{1/3} + A_t^{1/3})^2 - 7(N_t - Z_t)(A_p - Z_p)/A_t - Q}$$

with

$Q = |Q_1| + |Q_2|$,

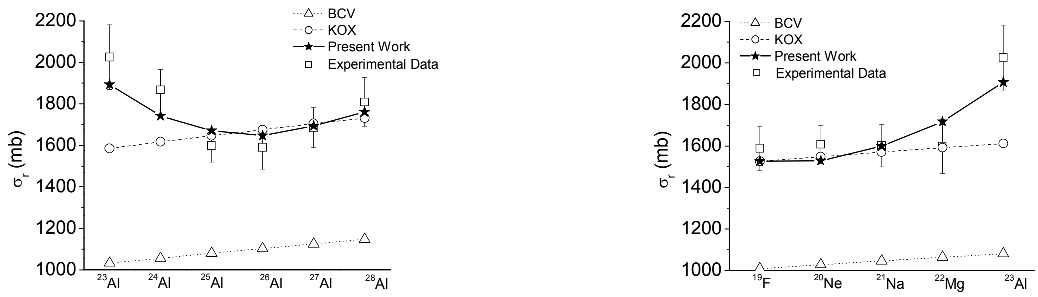
$Q_1 = (N_p - Z_p)(N_p - Z_p - 1) Z_p/(5 N_p)$,

and

$Q_2 = (N_p - Z_p) Z_p/(3 N_p)$, the $N_{p(t)}$ being the number of neutrons in the projectile (target). It is worth mentioning that the asymmetry factor F_{asym} has been obtained by fitting the reaction cross section data of reactions involving neutron/proton rich nuclei.

Upon comparing the σ_r obtained with BCV, KOX and present parameterization scheme i.e. eq. (1) with the corresponding experimental data of $^{12}C + ^{12}C$ system at different incident beam energies [2, 4, 5], the excellent agreement observed between the results obtained through the present parameterization scheme and the experimental data validates the fitting procedure [6].

Recently the structure of ^{23}Al , a proton rich nucleus and possible candidate for one-proton halo, has attracted a lot of attention and is an issue of critical debate for both theorists as well as experimentalists [7-10]. The observed large size of ^{23}Al is sometimes attributed to the possible existence of proton halo and other times to the existence of a large sized ^{22}Mg core. However, in either case it becomes exotic nucleus. In addition, the observed enhanced σ_r as compared to that of neighboring isotopes (Z =13) [7, 8] and isotones (N =10) [7, 8] has created further interest in ^{23}Al. So, we have also studied this nucleus with in the present scheme. The σ_r calculated through BCV, KOX and present scheme for these isotopic and isotonic chains along with the corresponding experimental data are shown in fig. 1(a) and (b). Clearly a good agreement between the experimental data and present calculations has been found. Furthermore, it is to be noted that the present scheme is able to reproduce the "arc" like trend as expected to be exhibited by any isotopic chain if it extends from proton-rich to neutron-rich nuclei. In case of isotopic chain the results obtained from KOX scheme are reasonably good in explaining the σ_r data for normal and neutron-rich isotopes of Al but it fails to explain the data of proton rich isotopes. The Same behavior is observed for isotonic chain [see fig. 1 (b)]. It is quite important to notice that the results obtained from BCV parameterization scheme substantially underestimate the σ_r data in case of both isotopic and isotonic chains.



(a) (b)

Fig. 1 (a) Comparison of σ_r obtained from BCV, KOX and present scheme with the corresponding experimental data taken from ref. [8] for the isotopic chain (Z =13) at 30 MeV/A. (b) Same as fig. 1 (a) but for isotonic chain (N =10).

In addition to the isotopic and isotonic chains of Al, the results of the present scheme are found to be in better agreement with the corresponding experimental reaction cross section data in comparison to those of other schemes considered here over a wide range of intermediate energies, for variety of normal and exotic nuclei and various targets (A =12-208) [6]. To conclude, the value of σ_r required for various purpose can be readily obtained with more authenticity using this scheme.

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