Determination of reaction cross section of carbon isotopic chain using phenomenological approach

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Total nuclear reaction cross section (σ_r) is an observable of paramount importance for extracting some of nuclear properties like nucleon density distributions, nuclear sizes of normal and exotic nuclei etc. Owing to the simplicity the phenomenological parameterization scheme for the calculation of σ_r is employed frequently. However, there exists large uncertainty in the determination of R_{int}, the interaction radius, which is an important ingredient needed in this scheme. In order to get accurate value of σ_r this uncertainty needs to be removed. Hence in the present work we have attempted to resolve this uncertainty by using recently proposed parameterization scheme for determining the safe lower limit of impact parameter ($b_{\min}$) [1]. We have taken the geometrical formula of KOX [2] as our base formula which is given as

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

where $B = \frac{Z_p Z_t e^2}{1.3\,(A_p^{1/3} + A_t^{1/3})}$ 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. Fitting the experimental σ_r data at beam energies ranging from 30 -1000 MeV/nucleon for $^{12}C + ^{12}C$ system [2-4] through χ^2 minimization method after replacing R_{int} by $b_{\min}$ we obtain the following expression [5]

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

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 [5]

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

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). Here, the asymmetry factor F_{asym} has been obtained by fitting the reaction cross section data of reactions involving neutron/proton rich nuclei.

Comparison of the experimental σ_r data with the predictions of the proposed parameterization scheme along with those of BCV [6] and KOX [2] for various carbon isotopes incident on carbon target at low as well as high beam energies has been shown in fig. 1.

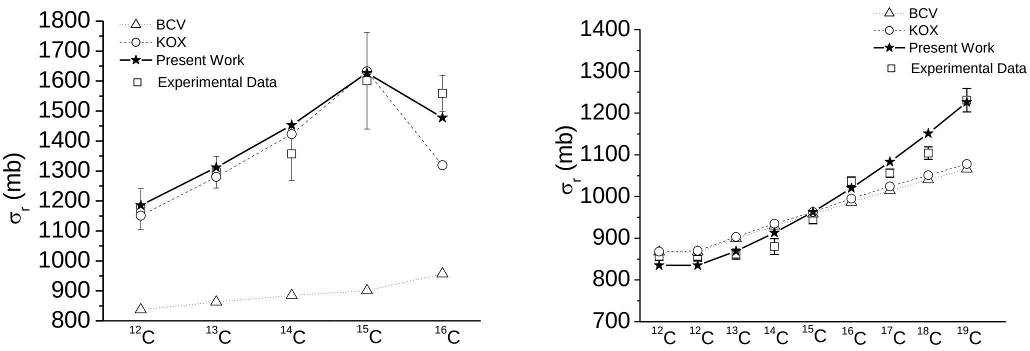

Fig. 1 (a) The reaction cross section calculated through BCV, KOX and present scheme for $^{12-16}C$ at incident beam energies ranging from 20-40 MeV/A [7]. (b) Same as fig. 1 (a) but for $^{12-19}C$ at 700-965 MeV/A energies [8].

For the intermediate energy range (20-40 MeV/A) [7] the initial increase in σ_r from ^{12}C to ^{15}C and the decrease in σ_r for ^{16}C is very well reproduced by the present scheme as shown in fig. 1. The larger value of σ_r for ^{15}C in comparison to the neighboring Carbon isotopes may be ascribed either to the lower energy or to the existence of neutron halo structure in this nucleus. It is worth mentioning here that the σ_r trend shown by $^{12-16}C$ isotopes is not only a function of projectile target combination but also a function of incident beam energy. Also the gradual increase in σ_r for the carbon isotopes for the higher energy range (700-965 MeV/A) [8] is successfully explained by the present scheme. These observations indicate that the parameterization scheme proposed here is appropriate for estimating σ_r for both intermediate as well as high energies. Further, it may be noticed from these figures that the present scheme explains the data better than BCV and KOX schemes. The BCV scheme substantially underestimates the σ_r data for intermediate energies while at high beam energies and for neutron rich isotopes of carbon both the BCV and the KOX schemes underestimate the data though to a small extent. Furthermore, the underestimation of data increases with increasing proton/neutron asymmetry. In addition to carbon isotopes this scheme may be used for a number other isotopes at wide energy ranges and for a number of projectile target combinations [6].

In summary, we have proposed a new parameterization scheme to determine σ_r in which the neutron and proton asymmetry is properly taken into account to explain σ_r data for neutron/proton rich nuclei. It has been found that this parameterization scheme reproduces the reaction cross section data very well over a wide range of energies, for carbon isotopic chain. Thus, the value of σ_r wherever required may be predicted with more authenticity using this scheme.

References

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