Analysis of proton-^{12}C reaction cross sections in the energy range 20-1000 MeV

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Introduction

Over the past about three decades, we have witnessed an increasing interest in experimental as well as theoretical studies of the total reaction cross section (σ_R), which is one of the most important physical quantities characterizing the nuclear reactions. Experimental reaction cross sections of proton scattering from nuclei are of fundamental importance to our understanding of proton-induced reactions. They find applications in diverse research areas such as medicine and astrophysics, and thus their studies constituted one of the motivations for the determination of nucleon optical potentials. From theoretical point of view, the global potentials which are derived from the vast set of existing experimental data on elastic angular distributions, polarization, and spin-rotation parameters are not unique and manifest ambiguities; therefore one expects that the studies of σ_R may not only be helpful in minimizing the different ambiguities in optical model calculations, one can also get the better picture of the reaction mechanisms when different models provide equivalent descriptions of the elastic scattering data.

Keeping this in view, we, in this work, consider the analysis of proton-^{12}C total reaction cross sections in the energy range 20-1000 MeV. The analysis is based upon the Coulomb modified correlation expansion for the Glauber amplitude [1,2], whose first term involves scattering of all orders without any correlations amongst the target nucleons, wheras the other terms consider the effects due to correlations. Assuming the effects of correlations to be fairly small [3], we consider only the first term of the correlated Glauber amplitude. Moreover, the basic NN amplitude assumes the same form and also with the same values of its parameters as used in ref. [4]. Thus our calculations are parameter free. The calculations have been performed using the relativistic mean field (RMF) [5] and the electron scattering [6] densities for ^{12}C. Our aim is to see how far the predicted values agree with the experiment, and what could be said about the matter density distributions in the present context.

Formulation

The total reaction cross section of proton-nucleus collision is expressed as

$$\sigma_R = \int d\vec{b}\left(1 - \left|\exp(\, i\chi(\vec{b})\right|^2\right), \qquad (1)$$

where **b** is the impact parameter vector perpendicular to the beam direction, and $\chi($**b**$)$ is the phase shift function which, in this work, is calculated using the Glauber model.

According to Glauber theory, the phase shift function for p-nucleus elastic scattering is given by

$$e^{i\chi(\vec{b})} = \left\langle \psi_0 \left| \prod_{j=1}^{A} (1 - \Gamma_{pN}(\vec{b} + \vec{s}_j)) \right| \psi_0 \right\rangle, \qquad (2)$$

where ψ_0 is the intrinsic A-nucleon wave function of the target, and $\mathbf{s}_j$ is the projection of the jth nucleon coordinate in the plane perpendicular to beam direction. The profile function, Γ_{pN} , for pp and pn scatterings, is usually parametrized as

$$\Gamma_{pN}(\vec{b}) = \frac{1 - i\rho_{pN}}{4\pi\beta_{pN}} \sigma_{pN}^{tot} e^{-b^2/(2\beta_{pN})}, \qquad (3)$$

where ρ_{pN} is the ratio of the real to the imaginary parts of the forward pN scattering amplitude, σ_{pN}

is the pN total cross section, and β_{pn} is the slope parameter of the pN elastic angular distribution. If we ignore nuclear correlations [3], the phase shift function assumes the following form:

$$e^{i\chi(\vec{b})} \cong [1-\Gamma_{pp}(\vec{b})]^Z [1-\Gamma_{pn}(\vec{b}))]^N , \quad (4)$$

with

$$\Gamma_{pp(n)}(\vec{b}) = \int d\vec{r} \rho_{p(n)}(\vec{r}) \Gamma_{pp(n)}(\vec{b}+\vec{s}) , \quad (5)$$

where $\rho_{p(n)}$ is the proton (neutron) density distribution, and Z(N) is the number of proton(neutron) in the target.

Equation (1) has been modified to account for the deviation in the straight line trajectory of the Glauber model because of the Coulomb field. Following Faldt and Pilkuhn [7], this deviation can be incorporated by replacing b in the phase shift function by b' , which is the distance of the closest approach in Rutherford orbits and is given by:

$$kb' = \eta + (\eta^2 + k^2 b^2)^{1/2} , \quad (6)$$

where k is the incident momentum, and $\eta = 2\pi Ze^2 / hv$ is the Sommerfeld parameter with v the projectile velocity.

Results and discussion

Following the approach outlined above, we have calculated the proton-^{12}C total reaction cross sections in the energy range 20-1000 MeV. The parameters of Γ_{pp} and Γ_{pn}, namely σ_{pp}, σ_{pn}, ρ_{pp}, ρ_{pn}, β_{pp}, and β_{pn}, are taken from ref. [4]. For proton and neutron distributions in the target, we have used the RMF [5] and the electron scattering [6] densities. The results of such calculations, together with the experimental data [8,9], are shown in Fig. 1. The solid and dotted lines show, respectively, the predictions using the RMF and electron scattering densities. The results show fairly good agreement with the data in the considered energy range. Moreover, the results with electron scattering densities are as good as those with the RMF densities. Thus the present results show that the electron scattering and RMF densities are equivalent from the point of view of providing a satisfactory explanation of the σ_r data for proton-^{12}C scattering in the energy range 20-1000 MeV. Finally, it is interesting to note that our results are as good as those obtained using the optical-limit approximation (OLA) of the Glauber model [4], showing that though the OLA and the uncorrelated Glauber model are two independent approximations to the correlated Glauber model, they turn out to provide equivalent descriptions of the σ_r data considered in this work.

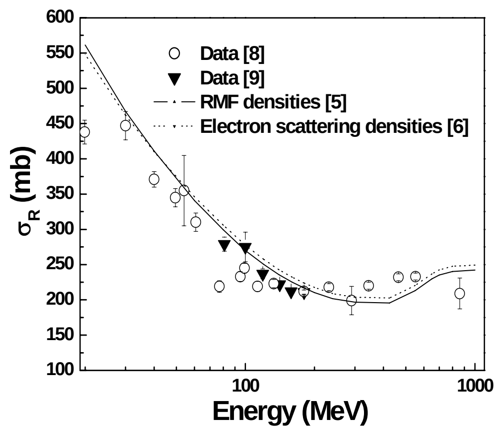

Fig. 1: Proton-^{12}C total reaction cross sections.

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