Study of p-^{16}O reaction cross section in the energy range 40-600 MeV and the effect of phase variation of the NN amplitude

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Introduction

Over the past many years, the Glauber multiple scattering theory (GMST) has been the most successful tool to analyze the differential cross sections and reaction cross sections of nucleon-nucleus and nucleus-nucleus collisions at intermediate energies. The results highlighted the importance of the successive higher order scatterings (nuclear correlations), especially the two-body correlation, and provide useful information about the matter density distributions in both stable and unstable (neutron-rich exotic) nuclei. In addition, the results also provided the significant information about the effects arising due to nuclear medium, higher momentum transfer components and the phase variation of the nucleon-nucleon (NN) amplitude.

In a recent work [1], it has been suggested that the use of Slater determinant description of colliding nuclei, involving harmonic oscillator single particle wave functions (hereafter referred to as SDHO densities), can be considered as a good starting point to predict the matter rms radii of stable as well as (exotic) neutron-rich nuclei. Keeping this in mind, we have predicted [2] the matter rms radii of oxygen isotopes that may account for the interaction cross sections of $^{16-24}$O on ^{12}C at ~ 1.0 GeV/nucleon. It is found that the matter rms radii of the considered oxygen isotopes deviate from those obtained using the relativistic mean field (RMF) approach. In order to test such predictions, we, in this work, propose to analyze the p-^{16}O reaction cross sections in the energy range 40-600 MeV within the framework of GMST. Our aim is to see how far the results of the present analysis are sensitive to different matter distributions of ^{16}O and what could be said about the matter rms radius of ^{16}O. Moreover, we have also studied the sensitivity of the results on the phase variation of the NN amplitude.

Formulation

According to the Glauber model, the elastic S-matrix describing the scattering of protons from a target nucleus is given by

$$S_{el}(\vec{b}) = (\psi_A | \prod_{i=1}^{A}[1 - \Gamma_{NN}(\vec{b} - \vec{s}_i) | \psi_A), \quad (1)$$

Where ψ_A is the target ground state wave function, $\vec{s}_i$ is the i^{th} nucleon coordinate in a plane perpendicular to the scattering (z) axis, and Γ_{NN} is the NN profile function, which is related to the NN amplitude $f_{NN}(\vec{q})$ as follows

$$\Gamma_{NN}(\vec{b}) = \frac{1}{2\pi ik} \int e^{-i\vec{q}.\vec{b}} f_{NN}(\vec{q})\, d^2q \qquad (2)$$

Following Ahmad [3], the S-matrix element S_{el} is written as

$$S_{el}(\vec{b}) = S_0(\vec{b}) + \sum_{l=2}^{AB} S_l(\vec{b}) \qquad (3)$$

The term $S_0(\vec{b})$ in eq. (3) gives the so-called optical limit approximation (OLA) (uncorrelated part). It depends upon the one-body density of the target nucleus, and it is this term that has been used in most of the applications of the Glauber model at intermediate energies. The higher order terms, $S_l(\vec{b})$, involve the l^{th} body density of the target nucleus and are considered as the corrections to the uncorrelated part.

With these considerations, the reaction cross section is calculated using the expression

$$\sigma_R = \int d^2b [1 - |S_{el}(\vec{b})|^2] \qquad (4)$$

Results and Discussion

We have calculated the reaction cross sections of protons on oxygen isotopes in the energy range 40-1000 MeV. The calculations consider terms up to two-body correlations in eq. (3). The inputs required in the calculation are **(i)** the NN scattering amplitude, **(ii)** the proton and neutron density distributions of the target nucleus, and **(iii)** the oscillator constants.

The NN scattering amplitude is usually parametrized in the form [1]

$$f_{NN}(\vec{q}) = \frac{k\sigma_{NN}}{4\pi}(i+\rho_{NN})e^{-(\beta_{NN}+i\gamma_{NN})q^2/2}, \quad (5)$$

where σ_{NN} is the NN total cross section, ρ_{NN} is the ratio of the real to the imaginary parts of the forward NN amplitude, β_{NN} is the slope parameter, and γ_{NN} is the phase variation parameter [4]. The present work needs the values of the parameters (σ_{NN}, ρ_{NN}, β_{NN} and γ_{NN}) in the energy range 40-1000 MeV. These values, except for γ_{NN}, are taken from Ref. [5]. The values of oscillator constants for proton and neutron SDHO distributions are fixed from the corresponding RMF rms radii for nuclei under consideration [1].

The results of the calculations are presented in Fig. 1. The squares and open circles correspond to SDHO and RMF densities, respectively, with no phase variation ($\gamma_{NN} = 0$) in the NN amplitude (eq. (5)). In both the cases the matter rms radii of oxygen isotopes are same [2]. As expected, the results with both the SDHO and RMF densities are not very different; such results are also observed in the interaction cross section calculations of $^{16\text{-}26}$O-^{12}C at 1.0 GeV/nucleon [2]. Next, we have considered SDHO predicted densities for which the values of oscillator constants are fixed by reproducing the interaction cross sections of $^{16\text{-}24}$O-^{12}C at 1.0 GeV/nucleon [2]. The results of such calculations are also shown by the triangles in Fig. 1 . It is found that the theoretical predictions in this case though move towards the experimental data in the low energy region, still large discrepancy is present between theory and experiment. Here it may be mentioned that the matter rms radius of ^{16}O, obtained using the SDHO predicted densities, though comes out to be closer to the one obtained in Ref. [5], but it deviates from that obtained using the electron scattering experiment [6] by about 7%.

Fig. 1 also shows the effects of the phase of the *NN* amplitude, which has been taken into account [4] by multiplying eq. (5) by the phase factor $e^{-i\gamma_{NN}q^2/2}$ and treating the phase of the *NN* amplitude γ_{NN} as a free parameter. Keeping the values of the parameters σ_{NN}, ρ_{NN} and β_{NN} the same, as used above, we find that the phase of the *NN* amplitude, γ_{NN}, helps in improving the results and provides excellent fit to the experimental data. Such results are shown by the open squares in Fig. 1 at some selected energies, and the values of the optimum γ_{NN} so obtained are also reported in the figure under the corresponding experimental data. Thus, the results of the present analysis show the importance of the phase of the NN amplitude, and suggest its need in the realistic calculations of reaction cross sections.

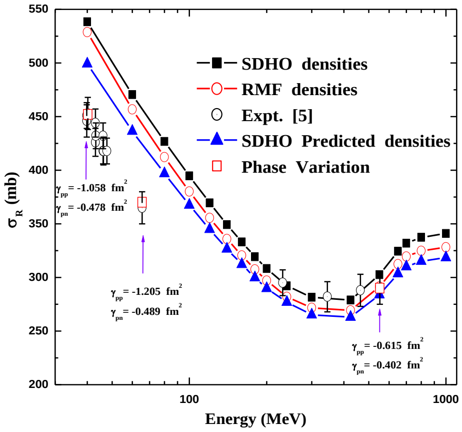

Fig. 1. p-^{16}O reaction cross sections.

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