^{16,20,21,23}O-^{12}C reaction cross sections at 1 GeV/nucleon

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Introduction

The production of (exotic) neutron-rich unstable nuclei near or at the neutron drip line and the reactions with a proton and nuclear targets has added an interesting topic in the field of nuclear structure physics. For stable nuclei, the electron scattering experiments provide reliable information about the proton density distribution, and the proton scattering experiments help in deducing information about the neutron density distribution in medium and heavy nuclei. However, the study of exotic nuclei encounter a serious problem due to the absence of electron scattering experiments for such nuclei. Thus, the available data on exotic nuclei is the only source to provide information about the matter density distributions of such nuclei, and predict their radii.

On the theoretical front, Glauber theory [1] offers a powerful and handy framework for the description of medium and high energy nuclear reactions. This theory has been quite successful in describing the proton-nucleus and nucleus-nucleus collisions. In recent past, Abu-Ibrahim *et al*. [2] have analysed the reaction cross-sections of oxygen isotopes on ^{12}C at 1 GeV/nucleon using the Glauber theory. The intrinsic proton and neutron densities of oxygen isotopes were calculated with Slater determinants constructed from harmonic oscillator wavefunctions. The calculations in Ref. [2] suffer from the weakness of treating the colliding nuclei on unequal footings and involving the optical limit approximation (OLA) which is not very justified for nuclei with low mass numbers. Keeping in view the limitations of the work presented in [2], we, in the present work, analyze the reaction cross sections of ^{16,20,21,23}O-^{12}C at 1 GeV/nucleon within the framework of conventional Glauber theory.

Formulation

According to the correlation expansion for the Glauber amplitude, the elastic S-matrix element S_{00} is written as

$$S_{00}\,(\mathbf{b}) = [1 - \Gamma_{00}]^{AB} + \text{Correlation terms} \quad (1)$$

with,

$$\Gamma_{00}(\mathbf{b}) = \frac{1}{ik}\int dq\;\; q\, J_0(qb) F_A(\boldsymbol{q}) F_B\,(\boldsymbol{q}) f_{NN}\,(\boldsymbol{q}), \quad (2)$$

where A and B are, respectively, the target and projectile mass numbers, **b** the impact parameter, $F_A(\boldsymbol{q})$ and $F_B\,(\boldsymbol{q})$ are the ground-state form factors of the target and projectile nuclei, respectively, at the momentum transfer q, and $f_{NN}(\boldsymbol{q})$ the elastic scattering amplitude for the free NN scattering at incident nucleon momentum k corresponding to the projectile kinetic energy per nucleon.

As observed in Ref.[2], the optical limit of the correlated Glauber model works reasonably well at 1 GeV/nucleon. This suggests that the nuclear correlations may not play a significant role in nucleus-nucleus collisions at the energy under consideration. Keeping this in mind, we may also use an alternative method in which we assume that the effect of nuclear correlations is fairly small, the Glauber model S-matrix element S_{00} can be obtained from eq.(1) after suppressing the correlation terms in it. With this assumption, the elastic scattering matrix element S_{00} may be written as

$$S_{00} \approx (1 - \Gamma_{00})^{AB} \quad (3)$$

Here, it should be pointed out that the distinction between protons and neutrons has also been incorporated in eq.(3). This modification leads to the following equation for the S-matrix

$$S_{00} \approx (1 - \Gamma_{00})^{Z_A Z_B} \times (1 - \Gamma_{00})^{Z_A N_B} \times (1 - \Gamma_{00})^{N_A Z_B} \times (1 - \Gamma_{00})^{N_A N_B},$$

where, Z_A (Z_B) is the atomic number of target (projectile) and N_A (N_B) is the number of neutrons in the target (projectile) nucleus. With this consideration, the reaction cross section is given by

$$\sigma_R = \int d^2 b \, [1 - |(1 - \Gamma_{00})^{AB}|^2] \quad (4)$$

Results and discussion

We analyze the reaction cross section of $^{16,20,21,23}O$ from ^{12}C at 1 GeV/nucleon using the uncorrelated part of the Glauber amplitude. The inputs needed in the theory are the elementary NN amplitude, and the density distributions for the colliding nuclei.

The NN scattering amplitude is usually parametrized in the following form

$$f_{NN}(q) = \frac{ik\sigma}{4\pi} (1 - i\rho) \exp\left(\frac{-\beta q^2}{2}\right), \quad (5)$$

where σ is the NN total cross section, ρ the ratio of the real to the imaginary parts of the forward NN amplitude and β is the slope parameter. The values of σ, β, and ρ at 1 GeV are taken from Ref.[3](Table1). The density distributions for the colliding nuclei are obtained using the approach outlined in Ref.[2], in which one assumes Slater determinant constructed from harmonic oscillator wavefunctions. The results of such calculations are presented in Table 2. Comparison of our results with those obtained in Ref.[2] shows that, except for ^{16}O, the conventional Glauber model calculations (without correlations) predict different values of reaction cross sections as compared to those obtained using the NTG approximation [2,4]. Moreover, it should be noted that the above mentioned results do not agree with the experimental values, we expect that a proper account of nuclear correlations and the use of realistic neutron density distributions may help in understanding the source of discrepancy.

Table 1: NN amplitude parameters at 1 GeV

σ_{pp} (fm^2)	σ_{pn} (fm^2)	β_{pp} (fm^2)	β_{pn} (fm^2)	ρ_{pp}	ρ_{pn}
4.63	**3.88**	**0.193**	**0.151**	**-0.09**	**-0.46**

Table2: The rms radii (in fm) of neutron and proton density distributions. The ν_p and ν_n values(in fm) are the size parameters of the harmonic oscillator functions for proton and neutron. The last three columns represent the reaction cross sections (in mb) for oxygen isotopes from ^{12}C at 1 GeV/nucleon.

	ν_p	ν_n	r_n	r_p	σ_R [2]	σ_R present	σ_R exp. [5]
^{16}O	1.71	1.71	2.51	2.51	1003	1003	982
^{20}O	1.70	1.83	2.94	2.51	1135	1176	1078
^{21}O	1.70	1.87	3.04	2.51	1173	1222	1098
^{23}O	1.70	1.98	3.30	2.51	1267	1337	1308

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