Analysis of p - ^{4,6,8}He scattering at 72 MeV

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Introduction

In the last decades, we have witnessed a great interest in the production and study of light neutron-rich nuclei up to and beyond the neutron drip line. One of the most exciting features of some of these nuclei is the neutron halo with dilute matter distribution far beyond the core of the nucleus. In exotic neutron-rich nuclei, the neutron halos correspond to one class of extended neutron distributions with an extremely long tail and appear only in nuclei with an extremely small separation energy of the last neutron(s). Although the density of a halo is very low, it significantly affects different reactions involving these nuclei. Another class of extended neutron distribution corresponds to neutron skins which refers to the difference of the proton and neutron density radii.

Effects of both neutron skin and halo were studied in ^{6}He, ^{8}He, and ^{11}Li by analyzing the elastic scattering of these nuclei on hydrogen [1,2]. In the inverse kinematics, this corresponds to proton scattering from the heavy ion, which directly measures the matter distribution of the ion. The results [1,2] indicate that the proton elastic scattering is sensitive to the matter extension in ^{6}He and ^{8}He, whereas the p-^{11}Li scattering is determined to a large extent by the proton scattering on the ^{9}Li core, reflecting a low- density in the neutron halo. Since the density of valence neutrons is lower in the ^{11}Li than in ^{6,8}He, the transparency of the halo for the incoming proton is larger in ^{11}Li than in ^{6,8}He, indicating neutron skin in ^{6,8}He.

In the present analysis, we propose to analyze the elastic scattering observables for protons from ^{4,6,8}He at 72 MeV. The purpose of this work is to study the sensitivity of the calculated observables for p-^{6,8}He scattering on the density distributions used. The analysis is based upon the well known Glauber formalism, which is found to provide satisfactory account of elastic nuclear scattering data at intermediate and also at relatively low energies.

Formulation

Neglecting the effects of nuclear correlations, the elastic S matrix element S_{el} may be written as [3]

$$S_{el} \approx (1-\Gamma_0)^A, \qquad (1)$$

with

$$\Gamma_0(\mathbf{b})=(2\pi ik)^{-1}\int e^{i\mathbf{q}.(\mathbf{b}-\mathbf{s})}\rho_A(\mathbf{r})\, f_{NN}(\mathbf{q})\, d^2q\, d\mathbf{r}, \qquad (2)$$

where A is the target mass number, **b** the impact parameter, **s** the projection of the target nucleon coordinate **r** on the plane perpendicular to beam direction , ρ_A is the ground state (one-body) density of the target nucleus, k the momentum of the incident nucleon, and f_{NN} is the elastic scattering amplitude for the NN scattering.

Here, it is to be noted that Eq. (1) has been modified to account for the (i) Coulomb effects, and (ii) deviation in the straight line trajectory of the Glauber model because of the Coulomb field [3].

Results and discussion

We analyze the elastic angular distribution and polarization for p-^{4,6,8}He scattering at 72 MeV. The inputs needed are the elementary NN amplitude and the density distributions for target nuclei. Following Alkhazov et al. [4], the NN amplitude is parametrized as

$$f_{NN}(q) = (ik\sigma/4\pi)\{(1-i\rho)\exp[-(\beta+i\gamma_c)q^2/2] +$$
$$i(q^2/4m^2)^{1/2}(1-i\rho_s)D_s\exp[-(\beta_s+i\gamma_s)q^2/2]\,\vec{\sigma}.\hat{n}\}, \qquad (3)$$

where σ is the NN total cross section, $\rho(\rho_s)$ the ratio of the real to the imaginary parts of the forward NN amplitude, $\beta(\beta_s)$ the slope parameter, D_s the relative strength of the spin-dependent amplitude, M the nucleon mass, $\gamma_c(\gamma_s)$ the phase parameter, $\vec{\sigma}$ the spin operator of the projectile, and $\hat{n}$ is the unit vector normal to the scattering plane. The values of σ, ρ, and β are taken from [5], [6], and [7], respectively. To know the values of D_s, ρ_s, and β_s, we consider ^{4}He as the test nucleus and fix their values by analyzing the p-^{4}He scattering data [8,9] at the required energy. The results of such calculations at 72 MeV are given in Fig. 1(a), and the values of NN parameters are given in table 1.

For ^{6}He and ^{8}He, we use the density distributions given in [1,2,10]. Using the same values of NN amplitude parameters as reported in table 1, we present the analysis of elastic p-^{6}He scattering data [11] and p-^{8}He scattering data [12] at 72 MeV in Fig. 1(b) and (c). It is found that the density distribution of [2] (solid lines) provides an overall better description of the experiment in ^{6}He, whereas ^{8}He results support the density distribution of [10] (solid lines), as compared to other distributions used. Thus we conclude that the results on ^{6}He and ^{8}He could provide a test to know which is the better choice of nucleon (especially neutron) density distributions.

Table 1

NN amplitude parameters at 72 MeV

NN	σ fm^2	β fm^2	ρ	γ_c fm^2
pp:	3.82	0.306	1.738	0.907
pn:	10.64	0.407	0.959	1.108

NN	D_s	β_s fm^2	ρ_s	γ_s fm^2
pp/pn	14.79	1.148	0.559	0.424

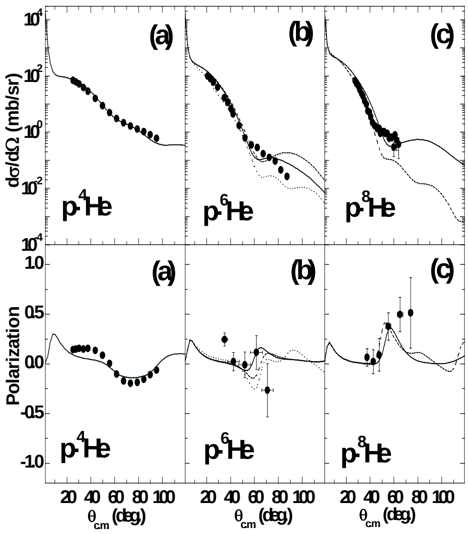

Fig. 1. p-^{4,6,8}He elastic angular distribution and polarization at 72 MeV.

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