Elastic scattering of 1.0 GeV protons on ^{40,42,44,48}Ca

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Introduction

One of the main objectives in the analyses of hadron-nucleus collisions at intermediate and high energies has been to extract information about the neutron density distribution, as the proton density distribution is fairly reliably known from the electron scattering experiments. On theoretical front, the Glauber model is found to provide a quite successful tool for such studies. One of the attractive features of Glauber model is that is connects the directly measureable (free) hadron-nucleon scattering amplitude to the hadron-nucleus one in a mathematically tractable way. In a recent work[1], our analysis of 1 GeV proton elastic scattering from light (N=Z) nuclei has demonstrated that the consideration of the better choice of the NN amplitude is able to provide a satisfactory account of the experimental data up to the available range of momentum transfer.

In this work, we present the (Coulomb modified) Glauber model analysis of the elastic scattering of 1 GeV protons on Ca isotopes using the similar form of the NN amplitude as proposed in ref.[1]. Our aim is to see how far the similar consideration[1] account for the data on the Ca isotopes, and what could be said about the neutron density distribution from such studies.

Formulation

Following Ahmad and Auger[2], the Coulomb modified[1] correlation expansion of the Glauber amplitude for describing the elastic scattering of protons with momentum **k** from a target nucleus in the ground state ($|\psi_0\rangle$) takes the form:

$$F_{00}(\vec{q}) = f_c(\vec{q}) + F_0(\vec{q}) + \sum_{l=2}^{A} F_l(\vec{q}) \quad (1)$$

$$F_0(\vec{q}) = \frac{ik}{2\pi}\int d^2b e^{i\vec{q}.\vec{b}} e^{i\chi_{pt}(\vec{b}')} [1-(1-\Gamma_0)^A e^{i\chi_c(\vec{b}')}], \quad (2)$$

$$F_l(\vec{q}) = -\frac{ik}{2\pi}\int d^2b e^{i\vec{q}.\vec{b}} e^{i(\chi_{pt}(\vec{b}')+\chi_c(\vec{b}'))} \times\langle\psi_0|(1-\Gamma_0)^{A-l}\sum_i\sum_{<j}...\sum_{<k}\gamma_i\gamma_j....\gamma_k|\psi_0\rangle \quad (3)$$

with

$$\gamma_j = \Gamma_0(\vec{b}') - \Gamma_{NN}(\vec{b}'-\vec{s}_j), \quad (4)$$

$$\Gamma_0(\vec{b}') = \langle\psi_0|\Gamma_{NN}(\vec{b}'-\vec{s}_j)|\psi_0\rangle, \quad (5)$$

where $\mathbf{s}_j$ is the projection of jth target nucleon coordinate $\mathbf{r}_j$ onto a plane perpendicular to **k**, and the NN profile function Γ_{NN} is related to the NN amplitude f_{NN} as:

$$\Gamma_{NN}(\vec{b}') = \frac{1}{2\pi ik}\int d^2q e^{-i\vec{q}.\vec{b}'} f_{NN}(\vec{q}). \quad (6)$$

The quantities $f_c(\mathbf{q})$, χ_{pt} and χ_c are the same as defined in ref.[3], and the distance of closest approach **b'**, that takes into account the deviation in the trajectory because of the Coulomb field, has the same expression as used in ref.[4].

In the present work, we restrict ourselves up to F_2 in the expression for F_{00} as it provides a leading correction to the optical limit[5] term F_0. More explicitly

$$F_2(\vec{q}) = \frac{i}{8\pi^3 k}\frac{A(A-1)}{2!}\int d^2b e^{i\vec{q}.\vec{b}'} e^{i(\chi_{pt}(\vec{b}')+\chi_c(\vec{b}'))} (1-\Gamma_0)^{A-2}[G_2 - G_0^2], \quad (7)$$

$$G_2 = \int d^2q_1 d^2q_2 e^{i(\vec{q}_1+\vec{q}_2).\vec{b}'} f_{NN}(\vec{q}_1) f_{NN}(\vec{q}_2) F^{(2)}(q_1,q_2) \quad (8)$$

and

$$G_0 = \int d^2q e^{-i\vec{q}.\vec{b}'} f_{NN}(\vec{q}) F(\vec{q}) \quad (9)$$

The quantities $F(\mathbf{q})$ and $F^{(2)}(\mathbf{q}_1,\mathbf{q}_2)$ in the above expressions are the one- and two-body (intrinsic) form factors respectively.

For the intrinsic two-body form factor $F^{(2)}(\mathbf{q_1,q_2})$, we use the following expression as derived in ref.[5].

$$F^{(2)}(\vec{q}_1,\vec{q}_2) = K(\vec{q}_1+\vec{q}_2) \left[\frac{F(\vec{q}_1)F(\vec{q}_2)}{K(\vec{q}_1)K(\vec{q}_2)} - \tilde{g}_c\left(\frac{\vec{q}_1-\vec{q}_2}{2}\right)D_M(\vec{q}_1+\vec{q}_2)\right], \quad (10)$$

where $K(\mathbf{q})$ is the c.m. correlation correction factor, and $\tilde{g}_c$ and $D_M(\mathbf{q})$ are the same as defined in ref.[5].

Results and Discussion

Following the above mentioned approach, we analyse the elastic angular distribution of 1 GeV protons on Ca isotopes. The inputs needed in the calculation are the elementary NN amplitude, the nuclear form factors, and the oscillator constants[5].

Following ref.[6], we parametrize the NN amplitude as follows:

$$f_{NN}(\vec{q}) = \frac{ik\sigma}{4\pi}\sum_{n=0}^{\infty} A_{n+1}\left\{\left(\frac{\sigma}{4\pi\beta^2}\right)^n \frac{(1-i\rho)^{n+1}}{n+1} e^{-\beta^2 q^2/2(n+1)} + i\left(\frac{q^2}{4m^2}\right)^{1/2}\left(\frac{\sigma}{4\pi\beta_s^2}\right)^n \times \frac{[D_s(1-i\rho_s)]^{n+1}}{n+1} e^{-\beta_s^2 q^2/2(n+1)}\vec{\sigma}.\hat{n}\right\} \quad (11)$$

where

$$A_{n+1} = \frac{A_1}{n(n+1)} + \frac{A_2}{(n-1)n} + \frac{A_3}{(n-2)(n-1)} + ... + \frac{A_n}{1.2}$$

with A_1=1. This amplitude has 6 adjustable parameters σ, ρ, β^2,Ds, ρ_s and β^2_s, whose values are chosen under the conditions that at 1GeV incident energy (i) the optical theorem be valid, (ii) the ratio Re f_{NN} (0)/ Im f_{NN} (0) be equal to the experimental value, and (iii) the experimental elastic angular distribution and polarization data for NN scattering be correctly reproduced.

For computational simplicity we parametrize the required nuclear form factors as a sum of Gaussians:

$$F(\vec{q}) = \sum_i a_i e^{-b_i q^2}$$

where a_i and b_i are parameters whose values are obtained by fitting the electron scattering form factors after correcting for the finite size of the proton. The values of oscillator constants are taken from ref.[7].

The results of calculations are presented in Fig.1. These calculations involve similar density distribution for protons and neutrons. It is seen that, except beyond the second diffraction minima, the data are nicely reproduced in all the cases. As pointed out in ref.[1], the results on ^{40}Ca supports different density distributions for protons and neutrons beyond the second diffraction minimum. One hopes that the similar

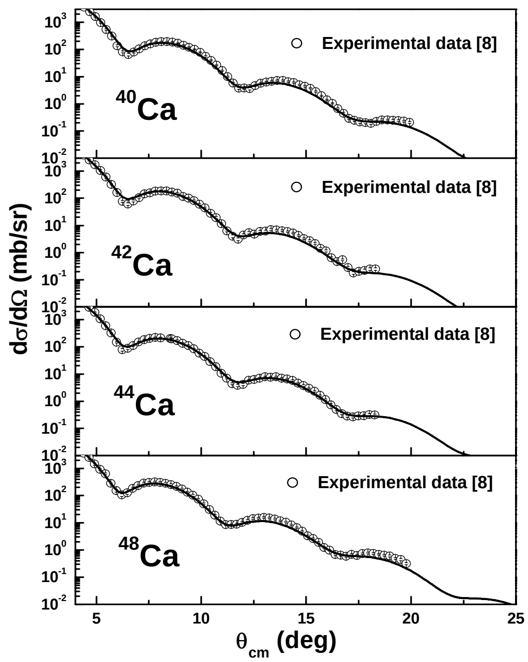

Fig.1 Angular distribution of p-Ca isotopes at 1 GeV

considerations may improve the situation in the case of Ca isotopes. The quantitative calculations involving realistic distributions for protons and neutrons in Ca isotopes are in progress.

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