Effect of nuclear densities on spin-rotation-function at 800 MeV

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Introduction

During last several decades, the Dirac phenomenology has emerged as a good tool to solve the nucleon-nucleus optical potential over a wide span of energies. The major characteristics of the non-relativistic optical potentials such as its central and spin-orbit parts are naturally included in the Dirac phenomenology. Moreover, the incorporation of relativistic dynamics is certainly necessary at medium energies.

The relativistic optical potentials obtained by Dirac phenomenology are found to be very sensitive to the nuclear ground state densities [1]. So, it paves a way to study the effects of nuclear structure on the overall fitting of the elastic scattering data. Keeping this fact in mind here we have used five different nuclear ground state densities of ^{40}Ca. These densities are represented here as LRAY, CHMX, IGO, NEG and FNEG. In this paper, we mainly focus on the role of these densities in the reproduction of the spin-rotation-function for p+^{40}Ca elastic scattering at 800 MeV.

The relativistic Dirac equation is simplified to an equivalent Schrödinger equation containing complex central (U_{eff}) and spin-orbit (U_{so}) optical potentials [2]. These U_{eff} and U_{so} potentials are further written in terms of the complex Lorentz scalar (U_s) and the time–like component of the complex Lorentz vector (U_0) potentials. The real parts of U_s and U_0 potentials are obtained through the folding procedure, where the matter densities of the target nucleus and the parameterized effective nn interactions are used as an input [2]. The respective imaginary parts of these potentials are directly taken from ref. [3].

The strengths of real and imaginary parts of complex U_s and U_0 potentials are multiplied with their respective normalization constants λ_s^r, λ_s^i, λ_v^r and λ_v^i (collectively called as λ's). The complex U_s and U_0 potentials are then renormalized varying λ's through chi-square minimization to fit the experimental data of elastic scattering observables.

Formalism

The Dirac equation is used in the mean field approximation by which the nucleon (meson) fields are replaced by their expectation values. Proton-nucleus scattering is then described using isoscalar-scalar and isoscalar-vector mean fields. Here, these are taken, respectively, as a spherically symmetric complex Lorentz scalar potential, U_S corresponding to the σ meson field and a spherically symmetric complex Lorentz vector potential, U_0 (time-like component of Lorentz four-vector) corresponding to the ω meson field, together with a spherically symmetric Coulomb potential V_c. With this scalar-vector interaction the Dirac equation becomes (ħ = c = 1),

$$\left[\vec{\alpha}\cdot\vec{p}+\beta\left\{m+U_s\right\}\right]\Psi=\left[E-U_0-V_C\right]\Psi, \qquad (1)$$

where Ψ is a four-component Dirac spinor with upper and lower components Ψ_U and Ψ_L, E is the total energy of the scattered nucleon in the c.m. frame, $\vec{\alpha}$ and β are four Hermitian operators. The second order reduction for the upper component Ψ_U yields,

$$\left[p^2+U_{eff}+U_{so}\left\{\left(\vec{\sigma}.\vec{L}\right)-i\left(\vec{r}.\vec{p}\right)\right\}\right]\Psi_U=\left[\left(E-V_C\right)^2-m^2\right]\Psi_U. \qquad (2)$$

The effective central potential U_{eff} is given by

$$U_{eff} = \frac{1}{2E}\left[2EU_0 + 2mU_S - U_0^2 + U_S^2 - 2V_C U_0\right], \quad (3)$$

where, $-2V_C U_0$ is the Coloumb correction term. The corresponding spin-orbit term U_{so} is,

$$U_{SO} = -\frac{1}{2E}\left\{\frac{1}{r}\frac{1}{E + m + U_s - U_0 - V_C} \frac{\partial}{\partial r}\left[U_s - U_0 - V_C\right]\right\}. \quad (4)$$

It is worth noting that the Coulomb correction and spin-orbit terms both appear naturally in the Dirac formalism whereas they are ad hoc in the Schrödinger formalism.

Result and Discussion

First we generated the scalar (U_s) and vector (U_0) potentials corresponding to the five different nuclear ground state densities [2] which are being used here. Once these potentials for each density are obtained then we solve eq. (2) for $p+^{40}Ca$ elastic scattering at 800 MeV using chi-square minimization varying the strengths of these complex U_s and U_0 potentials for the best fit to the differential cross-section ($d\sigma/d\Omega$) and the analyzing power (A_y) data. Here, intentionally we have not included the spin-rotation function (Q) data in the fitting. We just want to see to what extent the Q obtained from the fitting of differential cross-section and analyzing power reproduces its experimental data. It is always expected from relativistic treatment to give a good prediction of the Q data without including it into the fitting.

Almost all the results obtained with different nuclear densities reproduce the $d\sigma/d\Omega$ and A_y data adequately Fig.1(a) &(b). But as far as the Q data is concerned the results are not as expected. The calculated Q corresponding to LRAY and FNEG densities give satisfactory reproduction of the data Fig.1(c). While in case of other three densities namely CHMX, IGO and NEG even the structure of the Q data is not reproduced Fig.1(c). Earlier, we have carried out the same analysis at 200 and 500 MeV [1, 4] and the results particularly in case of CHMX and IGO densities successfully reproduced the Q data. It shows that the spin-rotation function is very sensitive to the structure of the nuclear ground state densities at this energy i.e. 800 MeV. We cannot attribute this behavior of our results to any other reason since it is only the densities in our calculations which are different. Further, the intrinsic relativistic behavior as is often claimed to give a reasonably good predictions of Q on the basis of the fitting of $d\sigma/d\Omega$ and A_y data, is not apparent here in case of CHMX, IGO and NEG densities Fig. 1(c). So, it seems that the calculated Q sensitively depends on the ground state densities of the target nucleus as well. But, on the other hand, the satisfactory reproduction of the Q data, as is obtained here for LRAY and FNEG densities, may see Fig. 1(c), is whether due to the relativistic formalism of the treatment or is just a merit of the involved densities, is a point to ponder.

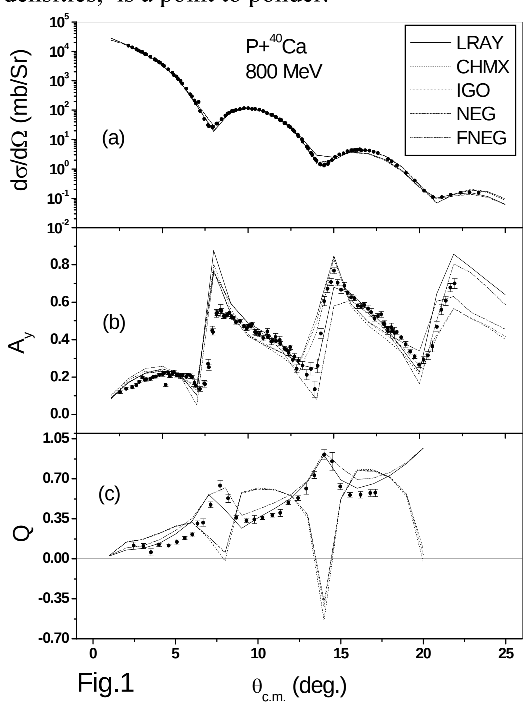

Fig.1

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