Relativistic analysis of spin-orbit potentials at 800 MeV

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Introduction

Over last many decades the elastic scattering data has extensively been analyzed with relativistic and non-relativistic approaches. All these formalism are almost equally successful in reproducing the data. But the relativistic formalism is somewhat more authentic and has an edge over the non-relativistic approaches, especially in reproducing the spin observables at intermediate energies. The self emergence of the spin-orbit potential in the second-order reduction of the Dirac equation to a Schrödinger equivalent equation makes it more fascinating and encouraging.

Here we analyze the $\vec{p}$ + ^{40}Ca elastic scattering at 800 MeV under the domain of the relativistic Dirac phenomenology with two different point-like nuclear matter densities namely NEG and FNEG [1]. NEG is purely microscopic point like density and the FNEG is same as the NEG density but with the finite size correction incorporated into it [1]. The advantage of using these two densities is that any inconsistency in the results may directly be attributed to the difference in the densities.

Since the Dirac equation deals quite adequately with the spin-orbit potentials, so here our main emphasis would be to analyze the effects of the finite size corrections on the spin-orbit potentials. This in turn is more likely to influence the spin-observables such as analyzing power (A_z) and spin-rotation function (Q).

Formalism

The formalism of our approach is very well known [2] so a brief account of this is as follows.

The relativistic Dirac equation is written containing scalar (U_s) and the four-vector (U_v) potentials only. In terms of these potentials the Dirac equation would be spherically symmetric for spin zero targets (e.g. ^{40}Ca). The contribution from the tensor terms is always negligible. This Dirac equation is simplified to a Schrödinger equivalent form with U_{eff} and U_{so} as the complex central and spin-orbit optical potentials. The U_{eff} and U_{so} are obtained in terms of U_s potential and the time like component of the four-vector potential i.e. U_0 [2]. Now, the main task is to generate these complex U_s and U_0 potentials. The real parts of these potentials are calculated by folding the scalar and vector nucleon-nucleon effective interactions over the respective point like nuclear matter densities [2]. The imaginary parts are taken from ref. [3]. Once U_{eff} and U_{so} are obtained the equivalent Schrödinger equation can be solved for the wave function $\phi(\vec{r})$. Now, the scattering amplitude is evaluated in terms of the complex central and spin-orbit parts as:

$$f(\theta) = A(\theta) + B(\theta)\vec{\sigma}.\hat{n} \qquad (1)$$

Using eq. (1) the scattering observables such as differential cross-section ($d\sigma/d\Omega$), analyzing power (A_z) and spin-rotation function (Q) defined as;

$$\frac{d\sigma}{d\Omega} = |A|^2 + |B|^2, \qquad (2)$$

$$\vec{A}_Z = \frac{2\,\mathrm{Re}\,AB^*}{|A|^2 + |B|^2}\vec{n}, \qquad (3)$$

$$Q = \frac{2\,\mathrm{Im}\,AB^*}{|A|^2 + |B|^2}, \qquad (4)$$

may easily be calculated.

The strengths of the complex scalar (U_s) and the vector (U_0) potentials are multiplied with the normalization constants (i.e. λ_r^v, λ_i^v, λ_r^s and λ_i^s). The values of these constants are obtained by the chi-square fitting to the experimental data. These values lie between 0 and 1. If they are close to 1 would mean that the calculated optical potentials are more reliable and correct.

Results and Discussion

It is quite obvious from Fig. 1(a) that the analyzing power (A_z), obtained with NEG and FNEG densities, are in good agreement with the experimental data. But the spin-rotation function (Q) data is very inadequately reproduced with the NEG density although FNEG density reproduces it quite well, Fig. 1(b). The only difference between NEG and FNEG densities is of nucleon finite size correction. So, it clearly implies that the Q data is more sensitive to this correction. The results remain unchanged whether Q data is included in the fitting together with the A_z and $d\sigma/d\Omega$ data or not. In figs.1&2 the graphs, obtained when Q data is also included in the fitting, are represented by (SRF).

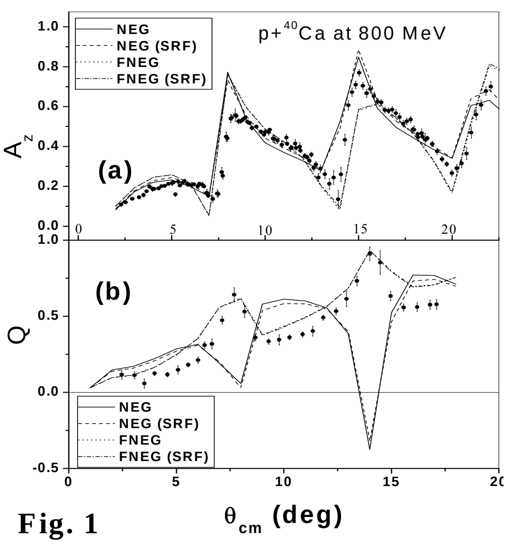

Fig. 1

The spin-orbit potentials corresponding to the densities under consideration are shown in Fig. 2(a). It is quite clear that the peak values of the ImU_{so} calculated with NEG and FNEG densities are distinctly different in magnitude (i.e. 0.2623 and 0.0656 MeV respectively). Obviously, it is much greater in case of NEG density. Reverse is the situation with ReU_{so}. Its maximum peak value, calculated with FNEG density, is -0.3269 MeV whereas in case of NEG density it is only -0.149 MeV. Marginal shift in these values are observed if Q data is included in the fitting, Fig. 2(a). But these differences in magnitude do not matter as much as the position of the peaks in their radial distribution. The peaks of Re. & Im. U_{so}, calculated with FNEG density occur at 3.0 fm whereas they appear at 3.4 fm when calculated with NEG density. This difference of 0.4 fm may affect the results noticeably. The radial position of these peaks remains almost unchanged even if Q data is included in the fitting, Fig. 2(a).

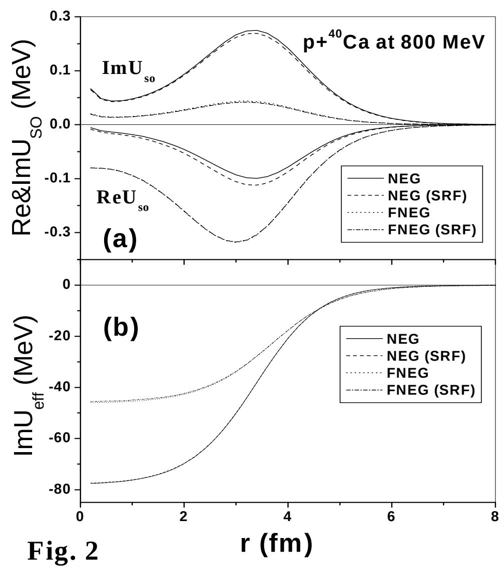

Fig. 2

There is a vast difference between the imaginary potentials (ImU_{eff}) calculated with and without finite size corrections at 800 MeV, Fig. 2(b). This difference particularly in surface region may affect the quality of the results. It is clear from eq. (4) that Q is defined in terms of imaginary parts only. So, the changes in the imaginary potentials due to the different nuclear ground state densities manifest itself predominantly in the predictions of the Q data, Fig.1. It leads us to conclude that the ImU_{eff} and ImU_{so} potentials calculated with the nucleon finite size corrections are more realistic and hence result in a good reproduction of the Q data as is the case with FNEG densities, Fig. 1.

References

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