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4.14 Relativistic Description of Deuteron Elastic Scattering at Intermediate Energies

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Recently measurements of cross section and polarization for deuteron elastic scattering at intermediate energies have been reported[1]. At lower energies, $E_d \leq 80$ MeV, to obtain a quantitative description of the data in terms of the interaction of the individual neutron and proton with the target nucleus the simplest approach is to use the folding model. At intermediate energies the nucleon-nucleus (NA) interaction can be described either in a nonrelativistic optical model or using the Dirac optical model phenomenology. Recent work has shown that the relativistic impulse approximation folding model for the NA Dirac equation provides a good description of NA scattering, particularly of the spin observables.

The present work describes an attempt to obtain a spin 1 relativistic equation for deuteron scattering with deuteron-nucleus interactions derived from the NA Lorentz invariant interactions. Instead of starting from the Breit equation[2] for 2 Dirac particles we search for a spin 1 equation following an approach analogous to the derivation of the van der Warden equation for spin 1/2. For spin 1 the fundamental relation is $x^3 = \vec{p}^2 x$ where $x = \vec{s}.\vec{p}$ and $\vec{s}$ is the spin vector operator. Starting from the relativistic relation $E^2 = \vec{p}^2 + m^2$ (in natural units) we obtain the identity

$$(x(x-E)x(x+E)+m^2x^2)\phi = 0. \tag{1}$$

In analogy with the van der Warden equation we rewrite eq(1) in the form $AB\phi = m^4\phi$. This condition gives

$$\left[m^2+2x(x-E)\right]\left[m^2+2x(x+E)\right]\phi=m^4\phi \tag{2}$$

or equivalently

$$\left[E^2-\vec{p}^2+2x(x+E)\right]\phi= m^2\chi \quad , \qquad \left[E^2-p^2+2x(x-E)\right]\chi= m^2\phi \tag{3}$$

where the 3 component spinors ϕ, χ also satisfy the Klein-Gordon equation. Eq.(3) is the Weinberg[3] equation for spin 1 in the chiral representation. Transforming to the Dirac representation we obtain

$$\begin{bmatrix} -(E^2-p^2+2x^2)+m^2 & 2Ex \\ 2Ex & -(E^2-p^2+2x^2)-m^2 \end{bmatrix} \begin{bmatrix} \psi_A \\ \psi_B \end{bmatrix} = 0. \tag{4}$$

For low energy ψ_B is smaller than ψ_A since $\psi_B=\left[Ex/(m^2+x^2)\right]\psi_A$. With plane waves

$$\left[x/(m^2+x^2)\right]\psi_A=(x/E^2)\psi_A \tag{5}$$

and therefore $\psi_B=(x/E)\psi_A$. Introducing vector V_v and scalar V_s interactions, E and m in eq (4) are replaced by $E'=E-V_v$ and $m'=m+V_s$. The resulting equation can be used to solve the scattering problem in the eikonal approximation . Another approach is to obtain a Klein-Gordon type equation for ψ_A. For low energy scattering we make an approximation based on eq.(5) and write $\psi_B \cong \left[2(E'^2+mV_{CO})\right]^{-1}(xE'+E'x)\psi_A$ where

$$V_{CO}=V_s+(E/m)V_v+(2m)^{-1}(V_s^2-V_v^2). \tag{6}$$

Finally substituting into the first of eqs(4) gives in Schroedinger form

$$\left[\frac{p^2}{2m} + V_C + V_{SO}\,\vec{\ell}\cdot\vec{s} + V_{TR}\,T_r + (2m^2)^{-1}\,T_p(v) - \frac{E^2 - m^2}{2m}\right]\psi_A = 0\ , \tag{7}$$

$$V_C = V_{CO} + (2/3)V_{TR} + 2V_{SO}\ , \tag{8a}$$

$$V_{SO} = \frac{1}{2m^2}\left[\frac{m}{E-V_v}\left(1+\frac{v}{m}\right)\frac{1}{r}\cdot\frac{dV_v}{dr} + \frac{1}{4r}\,\frac{dv}{dr}\right]\ , \tag{8b}$$

$$V_{TR} = \frac{1}{2m^2}\left[\frac{m}{E-V_v}\left(1+\frac{v}{m}\right)\left(\frac{d^2V_v}{dr^2} - \frac{1}{r}\,\frac{dV_v}{dr}\right) + \frac{3m}{2(E-V_v)^2}\left(1+\frac{v}{m}\right)\left(\frac{dV_v}{dr}\right)^2 + \frac{1}{E-V_v}\,\frac{dv}{dr}\,\frac{dV_v}{dr} + \frac{d^2v}{dr^2} - \frac{1}{r}\,\frac{dv}{dr}\right]\ , \tag{8c}$$

$$v = -\,m^2V_{CO}\left[(E - V_v)^2 + mV_{CO}\right]^{-1}\ , \tag{8d}$$

$$T_r = (\vec{s}\cdot\hat{r})^2 - 2/3\ , \qquad T_p(v) = v\,(\vec{s}\cdot\vec{p})^2 + (\vec{s}\cdot\vec{p})^2 v\ . \tag{8e}$$

It is important to emphasize that the spin dependent interactions in eq(7) arise exclusively from Lorentz invariance and have no relation with the deuteron internal structure. To obtain a prediction for the deuteron $V_v(d)$ and $V_s(d)$ potentials the most simple "folding model" approximation is to assume that

$$V_v(d) \cong 2V_v(p), \qquad V_s(d) \cong 2V_s(p) \tag{9}$$

where $V_v(p)$, $V_s(p)$ are the proton potentials at half the kinetic energy. Angular distributions[1] of $\sigma(\theta)$, $A_y(\theta)$, $A_{yy}(\theta)$ for $^{58}N_i$ and ^{40}Ca were analyzed using the eikonal approximation[4] and eq(9). The geometry of the scalar and vector proton potentials, given by Woods-Saxon forms, was kept fixed and only the strength was varied. We obtain a reasonable description of $\sigma(\theta)$ data. However the strength of the V_{SO} potential predicted by eq(8b) is too weak to reproduce $A_y(\theta)$ and $A_{yy}(\theta)$, probably because of the crudeness of the approximation (9). The result of calculations using proton potentials with the same geometry as in Ref.4, namely R=3.55fm, a=0.64fm and strengths of V_s^o and V_v^o respectively (-360+i65)MeV and (255-i75)MeV, are shown in Fig.1.

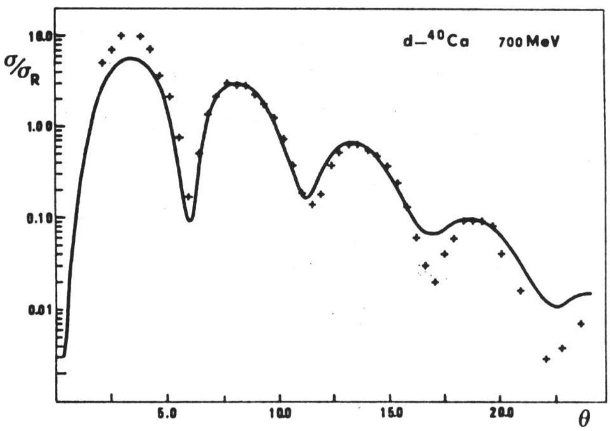

Fig. 1 Rutherford reduced deuteron cross section from ^{40}Ca at 700 MeV compared to calculations with the Weinberg spin 1 equation as described in the text.

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