DEUTERON POLARIZATION DETERMINATION AT HIGH ENERGIES

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In the event that polarized deuterons will be accelerated to high energy, to enable a spin study of neutron collisions for example, there will be a need to evaluate the level of polarization. Measurement of the analyzing power for polarized deuteron carbon collisions provides a method for the relative calibration of polarization when scattering angles are close to those of the electromagnetic hadronic interference region of momentum transfer. The use of carbon recoils has been effective in the case of the relative polarimetry for high energy spin half protons. A theoretical analysis of the corresponding process involving spin one deuterons scattering on a spin zero carbon target is presented. The nuclear effects associated with small angle polarized deuteron carbon collisions are incorporated.

1. Introduction

Considerable progress has been made in using polarized protons to elicit the partonic spin structure of the nucleon. To provide a more complete picture of the isotopic spin sector[1] it may be beneficial to use a probe more rich in the down quark such as the deuteron or a helium-three ion. The possibility of using deuteron carbon elastic scattering in the small angle interference region as a deuteron polarimeter is explored. Expectations for the anlyzing power are presented and discussed.

2. Helicity amplitudes

The parity conserving and time reversal invariant helicity amplitudes for a spin one deuteron of mass m scattering elastically off a spinless carbon nucleus are [2]

$$\begin{aligned} H_1 &= H_{++} = H_{--}\ , \qquad & H_2 &= H_{+\,0} = H_{0\,-} = -H_{0\,+} = -H_{-\,0} \\ H_3 &= H_{+-} = H_{-+}\ , \qquad & H_4 &= H_{0\,0} \end{aligned} \tag{1}$$

where the subscripts refer to the helicity states of the scattered and incoming deuteron respectively. With centre of mass three momentum k the spin averaged and spin aligned total cross sections are normalized according to

$$\begin{aligned} 4\pi\,\mathrm{Im}\,[2H_1(s,0) + H_4(s,0)]/3 &= k\sqrt{s}\,\sigma_{\rm tot}(s)\,, \\ 8\pi\,\mathrm{Im}\,[H_1(s,0) - H_4(s,0)]/3 &= k\sqrt{s}\,\sigma_{\rm tot}^{\rm al}(s)\,. \end{aligned} \tag{2}$$

As in the case of proton proton elastic collisions there is a spin dependent amplitude $H_1 - H_4$ which does not vanish in the forward direction.[3]

3. Coulomb amplitudes

Interference phenomena result from the inclusion of electromagnetic effects due to one photon exchange. Omitting contributions from the quadrupole moment form factor $F_2^{\rm d}(t)$ as they involve a factor t, the helicity amplitudes for a deuteron of mass m colliding with a spin zero nucleus of charge Ze and electromagnetic form factor $F_0(t)$ are (including the low $-t$ approximation)

$$\begin{aligned}
\frac{H_1^{\rm em}}{Z\alpha F_0} &= \left(F_1^{\rm d}\,\frac{s-u}{2t} - G_1^{\rm d}\right)\left(1+\frac{t}{4k^2}\right) &&\approx\ F_1^{\rm d}\,\frac{s}{t} \\
\frac{H_2^{\rm em}}{Z\alpha F_0} &= \left[\left(F_1^{\rm d}\,\frac{s-u}{4} - \frac{t}{4}\,G_1^{\rm d}\right)\sqrt{\frac{1}{m^2}+\frac{1}{k^2}} - \right. \\
&\qquad\qquad \left. -\,\frac{k\sqrt{s}}{2m}\,G_1^{\rm d}\right]\sqrt{\frac{2}{-t} - \frac{1}{2k^2}} &&\approx\ F_1^{\rm d}\,\frac{s}{\sqrt{-2t}}\left(\frac{1}{m} - \frac{\mu_d}{2m_p}\right) \\
\frac{H_3^{\rm em}}{Z\alpha F_0} &= -\left(F_1^{\rm d}\,\frac{s-u}{4} + \frac{t}{4}\,G_1^{\rm d}\right)\frac{1}{k^2} &&\approx\ 0 \\
\frac{H_4^{\rm em}}{Z\alpha F_0} &= F_1^{\rm d}\,\frac{s-u}{4}\left(\frac{2}{t} + \frac{1}{m^2} + \frac{1}{k^2}\right) - G_1^{\rm d}\left[1 + \right. \\
&\qquad \left. +\frac{s-u}{4m^2} + \frac{t}{4k^2} + \left(\frac{1}{m^2}+\frac{1}{k^2}\right)\frac{t^2}{16k^2}\right] &&\approx\ F_1^{\rm d}\,\frac{s}{t}\,.
\end{aligned} \tag{3}$$

Two of the electromagnetic form factors of the deuteron have normalisation $F_1^{\rm d}(0) = 1$ and $G_1^{\rm d}(0)/m = \mu_d/m_p$ in units involving proton mass m_p.[4]

4. Spin observables

Observables for scattering initially polarized deuterons on carbon are [2]

$$\begin{aligned} I_0 \,\equiv\, t^{00}_{00} &= 2\,|H_1|^2 + |H_4|^2 + 4\,|H_2|^2 + 2\,|H_3|^2 \\ (i/\sqrt{6})\, t^{00}_{11}\, I_0 &= -\,\mathrm{Im}\, H_2^*(H_1 + H_4 - H_3) \\ (1/\sqrt{2})\, t^{00}_{20}\, I_0 &= |H_1|^2 - |H_4|^2 - |H_2|^2 + |H_3|^2 \\ (1/\sqrt{6})\, t^{00}_{21}\, I_0 &= \mathrm{Re}\, H_2^*(H_1 - H_4 - H_3) \\ (1/\sqrt{3})\, t^{00}_{22}\, I_0 &= 2\,\mathrm{Re}\, H_1^* H_3 - |H_2|^2 \;. \end{aligned} \tag{4}$$

In the case where the amplitudes $H_1 - H_4$ and H_3 are negligible at high energies and low momentum transfers, the asymmetry parameter is

$$i\sqrt{3}\, t^{00}_{11} = -\,\frac{2\,\mathrm{Im}\,\sqrt{2}\, H_2^*\, H_1}{|H_1|^2 + \frac{2}{3}\,\left|\sqrt{2}\, H_2\right|^2} \tag{5}$$

and the correspondence with the proton carbon case is evident.[5] It is useful to introduce the following hadronic amplitudes with kinematically scaled ratio $\tau(s,t)$ between helicity flip and helicity non flip hadronic amplitudes

$$F \;=\; \frac{1}{2\,k\sqrt{s}}\,\frac{2H_1 + H_4}{3}\,, \qquad \tau F \;=\; \frac{m_p}{2\,k\sqrt{s}}\sqrt{\frac{2}{-t}}\, H_2 \tag{6}$$

so that the analyzing power may be written using equation (3) as

$$\frac{A_N}{4\pi}\,\frac{d\sigma}{dt} = \frac{\sqrt{-t}}{m_p}\, 2\,\mathrm{Im}\,\left(F + F^{\,\mathrm{em}}\right)^*\left[\tau F + \left(\frac{\mu_d}{2} - \frac{m_p}{m}\right) F^{\,\mathrm{em}}\right] \tag{7}$$

where the deuteron carbon amplitudes comprise a hadronic part $F(s,t)$ and an electromagnetic part with $Z = 6$, form factor F_C, and Coulomb phase δ

$$F^{\,\mathrm{em}} = 6\alpha\, F_1^{\mathrm{d}}\, F_C\, e^{i\,\delta}/t\,. \tag{8}$$

If the proton carbon elastic scattering amplitude $f(q)$ is assumed equal to the neutron carbon amplitude, the deuteron carbon amplitude may be calculated at a particular value of s using an approximate Glauber method[5]

$$F(t) = 2\,f(q)\,f_d(q/2) + i\int \frac{d^2q'}{\pi}\, f(q/2 + q')\, f(q/2 - q')\, f_d(q')\,. \tag{9}$$

The figure shows the analyzing power for d–C scattering when there is no hadronic helicity flip amplitude. By comparison with the interference peak in proton carbon elastic scattering,[6] the smaller interference trough near $-t = 0.002$ GeV/c^2 results from the low negative value of the deuteron anomalous magnetic moment in addition to the inhibiting effect of total cross section ratios. The depth of the trough is very sensitive to the value of the hadronic helicity flip amplitude and can even change sign with moderate values. The figure of merit of the peak at higher $-t$ should also be studied in the context of polarimetry for deuterons. It seems likely that measuring the polarization of high energy deuterons presents an interesting challenge.

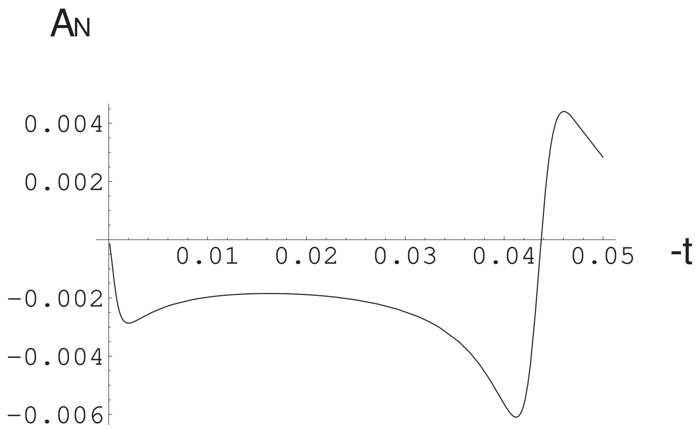

Figure 1. The analyzing power for d-C scattering with zero hadronic helicity flip.

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