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TENSOR POLARIZATION MEASUREMENT IN ELASTIC ELECTRON–DEUTERON SCATTERING AT LARGE MOMENTUM TRANSFER*

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The three tensor polarization components (t_{20}, t_{21} and t_{22}) of the recoil deuteron in elastic electron-deuteron scattering have been measured in the range of 4-momentum transfer Q = 4.1-6.8 fm^{-1}. The experiment was performed with the multi-GeV, high intensity electron beam available at the Jefferson Laboratory and using the tensor deuteron polarimeter POLDER. These new data are used to separate the charge G_C and quadrupole G_Q form factors at large momentum transfer and provide additional constraints on theoretical models.

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1. Introduction

The study of elastic $e-d$ scattering at large 4-momentum transfer gives us information on the deuteron structure at short relative distances between the nucleons. Since the deuteron has a spin 1, its electromagnetic structure is described by three form factors: charge monopole G_C, charge quadrupole G_Q and magnetic dipole G_M.

Complete knowledge of the 3 form factors require three independent observables. First the elastic differential cross-section can be written as

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\rm Mott} \cdot \mathcal{S} = \left(\frac{d\sigma}{d\Omega}\right)_{\rm Mott} \cdot \left[A(Q) + B(Q)\tan^2\left(\frac{\theta_e}{2}\right)\right], \qquad (1)$$

where $\left(\frac{d\sigma}{d\Omega}\right)_{\rm Mott}$ describes the scattering of an electron off a pointlike spinless particle. Q is the 4-momentum transfer to the deuteron and is related to the deuteron energy through the relation $Q^2 = 2\,M_d\,T_d$.

The structure functions A and B are in turn given in terms of the three elementary electromagnetic form factors:

$$A(Q) = G_C^2(Q) + \frac{8}{9}\eta^2 G_Q^2(Q) + \frac{2}{3}\eta G_M^2(Q)\,, \qquad (2)$$

$$B(Q) = \frac{4}{3}\eta(1+\eta)G_M^2(Q)\,, \qquad (3)$$

with $\eta = Q^2/4M_d^2$.

A third observable is thus necessary to separate the 3 form factors. Usually tensor polarization observables (t_{2i}) of the deuteron are measured [1–5]. The analyzing powers can be extracted from the asymmetries resulting of the elastic scattering of unpolarized electrons on a polarized deuteron target. Alternatively tensor polarization observables can be obtained by measuring the polarization of the recoil deuteron. One obtains then new combinations in terms of the electromagnetic form factors,

$$\begin{aligned} t_{20} &= -\frac{1}{\sqrt{2}\,\mathcal{S}}\left[\frac{8}{3}\eta G_C G_Q + \frac{8}{9}\eta^2 G_Q^2 + \frac{1}{3}\eta\left[1 + 2(1+\eta)\tan^2\left(\frac{\theta_e}{2}\right)\right]G_M^2\right], \\ t_{21} &= \frac{2}{\sqrt{3}\,\mathcal{S}}\,\eta\left[\eta + \eta^2\sin^2\left(\frac{\theta_e}{2}\right)\right]^{1/2} G_M G_Q \sec\left(\frac{\theta_e}{2}\right), \qquad (4) \\ t_{22} &= -\frac{1}{2\sqrt{3}\,\mathcal{S}}\,\eta G_M^2\,. \end{aligned}$$

The experiment reported here has extended the existing data set on t_{20} [4] up to 6.8 fm^{-1} and also provides a good determination of the G_C and G_Q

form factors near the node of $|G_C|$ around 4.2 fm^{-1} and its maximum around 5 fm^{-1}. Only a very good description of the short range interaction between the nucleons allows one to reproduce this feature. The t_{21} observable could also help for a new determination of the node of G_M around 7 fm^{-1}.

Concerning the models in our region of 4-momentum transfer (4-7 fm^{-1}), the impulse approximation approach, where the electron interacts with only one nucleon, is not likely to reproduce the data. It is well known that the inclusion of isoscalar meson-exchange currents (MEC) and isobar components (IC) will contribute significantly above 2 fm^{-1} [8]. Moreover different predictions from relativistic covariant models are now available in this Q range [9, 10]. Finally several calculations have been made within a perturbative quantum chromodynamics framework [11, 12].

2. Experimental setup

The experiment was performed in Hall C of Jefferson Laboratory and the set-up is shown in figure 1. A continuous electron beam of 100 μA was sent on a liquid deuterium target 12 cm long and 600 W cryogenic power. Typical luminosities of about $3. \times 10^{38}$ cm^{-2}s^{-1} were thus achieved. The experiment required two spectrometers for the detection of the scattered electron and recoiling deuteron in coincidence.

The outgoing electron was detected within a solid angle of about 6 msr in the HMS spectrometer. The reconstructed electron trajectories and momenta were used to calculate the vertex position at the primary target and the invariant mass in order to select properly the elastic scattering events. In addition the time difference between the electron and the deuteron has been used to reduce the contribution of the overall background (mainly coming from protons of deuteron break-up and random coincidences) to a negligible level (≤ 1 %).

A specific deuteron magnetic channel, composed of 3 quadrupoles and one dipole, has been built for this experiment. The purpose was to protect the polarimeter POLDER from the direct view of the primary target and to focus the maximum number of elastic deuterons on the liquid hydrogen target (14 cm in diameter) of the POLDER polarimeter. The mismatch factors between the two arms were between 1 to 0.5 depending on the deuteron energy. Since this deuteron magnetic channel was set at fixed angle, the six different Q values have been obtained by changing the beam energy between 1.4 and 4 GeV and the detection angle of the HMS spectrometer.

The polarimeter POLDER is based on the ^{1}H($\vec{d}$,2p)n reaction which provide sizeable experimental asymmetries depending upon the different tensor components of the incident deuteron polarization [6, 7]. The polarized effi-

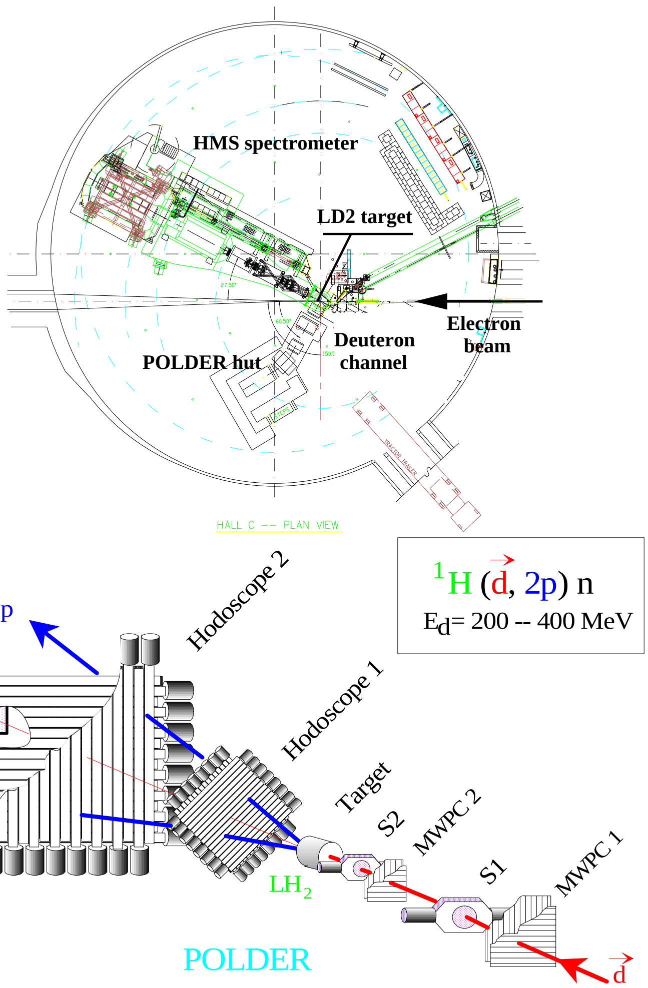

Fig. 1. Set-up of the t_{20} experiment in the hall C of Jefferson Laboratory and schematic view of the *POLDER* polarimeter.

ciency $\epsilon_{\rm pol}$ of the polarimeter obtained during the t_{20} experiment has to be compared to the unpolarized one ϵ_0 through the relation,

$$\epsilon_{\rm pol}\,(\theta,\varphi) = \epsilon_0(\theta)\Big(1 \; + \; t^d_{20}\;T_{20}(\theta) + 2\;\sin(\phi)\;it^d_{11}\;iT_{11}(\theta) \\ +2\;\cos(\phi)\;t^d_{21}\;T_{21}(\theta) + 2\;\cos(2\phi)\;t^d_{22}\;T_{22}(\theta)\Big)\,, \qquad (5)$$

where T_{kq} are the analyzing powers of the ${}^1{\rm H}(\vec{d},2{\rm p}){\rm n}$ reaction and t_{kq} the polarization coefficients of the deuteron. Here θ is the angle between the incident deuteron and the proton pair momenta and ϕ the angle between the normal to the reaction and the e-d scattering planes.

The polarimeter POLDER is composed of three parts (Fig. 1) [7]. First the direction and number of incident deuterons are measured with two MWPC's and two scintillators placed upstream of a 20 cm long liquid hydrogen target. Two hodoscopes, composed of bars of thin plastic scintillator, have been used to detect the two protons coming from the $^1\mathrm{H}(\vec{d},2\mathrm{p})\mathrm{n}$ reaction, which takes place in the target. The charge exchange efficiency is deduced using loose cuts on time-of-flight and angle information with a 1% stability. The analyzing powers T_{kq} and the POLDER unpolarized efficiency ϵ_0 have been measured previously at $SATURNE$ using polarized deuteron beams in the range between 140 and 520 MeV kinetic energies. Large figures of merit have been obtained for all three tensor polarization T_{20}, T_{21} and T_{22}, and the vector analyzing power T_{11} was measured to be 0.

3. Results

The preliminary results, obtained for the t_{20} observable, are shown in figure 2. The associated error bars include both statistical and systematic errors with conservative assumptions. At present the data points at 4 and 4.5 fm^{-1} are dominated by the errors on the reconstructed incident electron energy which result in uncertainties on the normalization of the POLDER unpolarized efficiency between 3 or 4 % . At 6.2 and 6.8 fm^{-1} the errors are also dominated by the low statistics despite of 1.5 months of data taking. It is expected that the error bars will be reduced by typically a factor 2 in the final analysis.

Our data are compared with previous data and with several theoretical predictions. Where the new data overlap with the earlier Bates data there is agreement within the combined uncertainties; although it would appear at this stage of our analysis that the new points may be systematically above the earlier data. Comparing with theory it is clear that neither of the PQCD predictions is borne out by the new data. The new data seem to favor the NRIA with MEC and relativistic corrections wheras the Bates data are in better agreeement with the "uncorrected" NRIA. The two relativistic models are in reasonable agreement with both the Bates and TJNAF data. The measurements at NIKHEF using a polarized internal deuterium target in the AMPS ring should be an important addition to the data base when they are extended to the region of the zero in Gc near 4.2 fm(-1) as they will provide a third experimental technique with different systematic errors.

During our experiment the measurement of the A(Q) structure function was also performed for the same six Q values . The final analysis should provide us data with an accuracy of about 4 % . Another experiment,

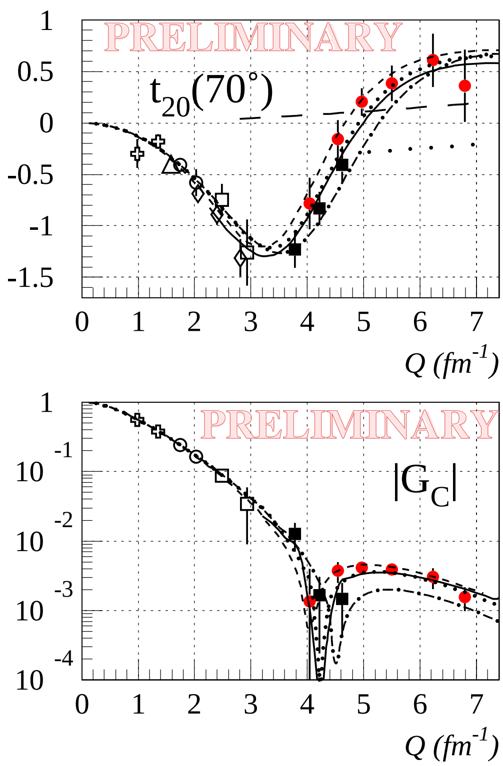

Fig. 2. $t_{20}(70°)$ and G_c. The data (full circles : this experiment; others experiments from references [1-5]) are compared to the theory (dotted-dashed (NRIA) and dashed lines (NRIA+MEC+RC) from [8]; relativistic models with dotted [9] and full [10] lines; PQCD calculations with long dashed [11] and long dotted [12] lines.

performed in the hall A of the Jefferson Laboratory, was dedicated to the measurement of A(Q) in a large Q range up to 15 fm^{-1}. These data should provide a stringent test of the quark counting rule derived by Brodsky *et al.* [13].

The new data on t_{20} and A(Q) can be used with the existing data on B(Q) in order to extract the 3 form factors of the deuteron. The preliminary results, shown in the figure 2, give a node for the charge form factor $|G_C|$ located around 4.2 fm^{-1} and $|G_C|$ values at the maximum close to the maximum values predicted by the theory.

4. Conclusions

We have measured the t_{20} polarization observable between 4.1 and 6.8 fm^{-1} in electron deuteron elastic scattering. The final analysis is in progress and should reduce the error bars by a factor 2. Our data on t_{20}, used in conjunction with new data on the structure function $A(Q)$, provide a good determination of the charge and quadrupole form factors. In particular the node of G_C, which is very sensitive to several theoretical ingredients like the inclusion of the meson exchange currents and relatistic effects, should be better constrained. Also the Q range covered by these data extends up to 7 fm^{-1} where the internal structure of the nucleons inside the deuteron could manifest itself.

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