Prospects for t_{20} with 12 GeV beam

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Abstract

Measurements of t_{20} in elastic *ed* scattering allow detailed study of the deuteron ground state structure. Jefferson Laboratory has recently measured t_{20} up to $\sim$7 fm^{-1}. It is possible, but difficult, to push polarization measurements to higher momentum transfer.

1 Introduction

The deuteron, as the only $A = 2$ nucleus, is a primary test case for microscopic models of nuclear structure. Elastic scattering is a direct way to measure the ground state structure, and to test predictions. A goal of deuteron experiments over the past several years has been to push measurements to higher momentum transfer, to distinguish between predictions based on nucleon physics and those based on short range quark physics. Unpolarized deuteron elastic scattering and the deuteron structure has been discussed in this workshop by G. G. Petratos.

The deuteron structure is described by charge, magnetic, and quadrupole form factors, G_C, G_M, and G_Q. Cross section measurements allow determination of G_M and a combination of G_C and G_Q. Measurements of B [2] show that G_M is small, and has a minimum near $Q^2 \sim 2$ (GeV/c)^2.

Assuming parity conservation and one photon exchange, there are five allowed polarization observables. Explicit formulas are given in [1]. t_{20} is favored for separating G_C and G_Q, in part because it can be measured with high intensity unpolarized electron beams. The vector polarization transfer component t_{10} (C_z) and the tensor polarization component t_{22} ($P_{xx} - P_{yy}$) depend on G_M^2, and thus are expected to be small. The vector polarization transfer component t_{11} (C_x) and the tensor polarization component t_{21} (P_{xz}) depend linearly on G_M, so these observables should go through 0 and change sign at $Q^2 \sim 2$ (GeV/c)^2. As a result, a small uncertainty on these polarizations may still lead to a large relative uncertainty on the extracted form factors.

In contrast, t_{20} (P_{zz}) depends on a sum of terms, and tends to be large. It has been measured with polarized targets [3] and recoil deuteron polarimeters [4]. The Hall C t_{20} collaboration [5] has recently extended the data to a four-momentum transfer range of 4 to 6.8 fm^{-1}, or 0.62 to 1.80 (GeV/c)^2. The *preliminary* data have uncertainties that are sufficient to confirm the minimum in G_C near 4 to 4.5 fm^{-1}, but are not sufficient to discriminate between all the recent relativistic and nonrelativistic calculations - simple pQCD based estimates are however ruled out.

2 Future Experiments

To measure further in Q^2, increased figure of merit is needed, either with greater count rate, or with polarization techniques requiring fewer events. The Jefferson Laboratory energy upgrade and E^2/Q^4 scaling of the cross sections leads in principle to an order of magnitude greater count rate.

For $Q^2 = 1.3$ to 3.7 (GeV/c)^2 ($\sqrt{Q^2} = 6$ to 11 fm^{-1}), and fixed 12 GeV beam energy, one uses a 12 GeV/c electron arm at 5 to 10°, and a 2.2 GeV/c deuteron arm at 60 to 70°. The difference in angles and momenta of these spectrometers leads to a large kinematic mismatch. A large acceptance deuteron spectrometer needs to focus all the deuterons onto a recoil polarimeter, while having sufficient resolution to separate ed elastic scattering from $ed\pi^0$ and other inelastic final states. Thus, it is very difficult to take full advantage of the increased count rate with energy.

Table 1 shows estimates of the count rates and polarization observables for fixed 12 GeV beam. The count rates assume a 100 μA beam incident on a 10 cm LH$_2$ target, with a 5 msr electron arm and full (unrealistic) coincidence efficiency. The polarizations are based on form factors extracted from existing data, and a smooth scaling with increasing momentum transfer. The change in sign of t_{11} and t_{21} results from the minimum in G_M. t_{10} is always small. The change in sign of t_{20} arises from the relative magnitudes of the $G_C G_Q$ and the G_Q^2 terms. Under this scenario, a recoil tensor polarimeter (see below) would allow measurements to be made up to about 9 fm^{-1}, as compared to the present 7 fm^{-1} maximum, in about a month.

What polarimeter to use in the future is an important issue. Few tensor polarimeters exist, and it is difficult to obtain polarized deuterons for calibrations with the shutdown of the SATURNE accelerator at Saclay.

Table 1: *Polarization observables and rates for 12 GeV* $ed \rightarrow ed$*, with* $d\Omega_e = 5$ *msr and without coincidence mismatch.*

q (fm^{-1})	dσ/dΩ (cm^2/sr)	t_{11}	t_{10}	t_{20}	t_{21}	t_{22}	rate (/hr)
6	1.8×10^{-34}	0.01	0	0.48	0.10	-0.00	9.1×10^{5}
7	2.5×10^{-35}	-0.01	0	0.35	-0.04	-0.00	1.3×10^{5}
8	3.4×10^{-36}	-0.02	0	0.16	-0.10	-0.00	1.7×10^{4}
9	4.9×10^{-37}	-0.07	0	-0.01	-0.28	-0.02	2500
10	6.8×10^{-38}	-0.04	0	-0.12	-0.14	-0.01	350
11	9.9×10^{-39}	-0.07	0	-0.22	-0.21	-0.01	50

The recent Hall C experiment [5] used POLDER, developed by S. Kox of Grenoble and collaborators [6]. Polarimetry, based on the $p(d,pp)n$ reaction, was extensively calibrated at SATURNE. A new experiment using such a polarimeter is not a good idea, as both analyzing power and efficiency decrease with energy, and no calibrations exist. In the Hall C experiment, the ultimate uncertainties of the highest momentum transfer point are limited by both polarimeter calibration uncertainties and statistics.

The HYPOM polarimeter is a vector and tensor polarimeter developed at Saclay by E. Tomasi-Gustafsson and colleagues [7]. It is an upgrade of the POMME polarimeter, with added detectors, and using dp elastic scattering in place of carbon inclusive scattering. Extensive Monte Carlo studies and some test measurements have been done, mostly in the range T_d = 1 - 2 GeV, as compared to the 0.5 - 1 GeV needed to extend t_{20}.

In the scattering of tensor polarized deuterons by an analyzer, t_{21} and t_{22} lead to cos(ϕ) and cos(2ϕ) azimuthal asymmetries, respectively. If the electron beam is polarized, there can be a helicity dependent vector polarization. The transverse component t_{11} leads to a sin(ϕ) asymmetry, whereas the longitudinal component t_{10} leads to no asymmetry, neglecting spin transport, and thus is not measurable. In contrast, t_{20} changes the scattering fraction. Determination of the absolute scattering fraction requires precise calibration, which is a difficult issue.

It might be interesting to measure vector polarizations, which has not been done, instead of t_{20}. Jefferson Lab has demonstrated the ability to deliver 100 μA of 40% polarized beam over extended periods; thus luminosities are the same as unpolarized beam measurements. There are several experimental advantages. The vector polarimetry figure of merit is several times as large as the tensor figure of merit, reducing the number of events needed. The vector polarizations depend on beam helicity, and one measures the helicity sum, which gives unpolarized deuterons that can be used to check polarimeter systematics, and the helicity difference, in which false asymmetries largely cancel. If both vector polarizations are large, the ratio gives a ratio of form factors, in which the analyzing power cancels. These benefits must however be weighed against the expected small vector polarizations that result from the small magnitude of G_M.

An alternative is polarized targets. The cross section is given by:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_0 [1 + T_{20}t_{20} + \cdots]$$

with

$$t_{20} = \frac{(1-3n_0)}{\sqrt{2}} P_2(\hat{n}\cdot\hat{q}).$$

Existing deuteron targets with $P_v = 40$ % vector polarization also have a tensor polarization $t_{20} = 0.04$, with $dt_{20}/dP_v = 0.002$ / %. For $T_{20} \approx 1$, this leads to an azimuthal asymmetry of -2 to +4%, depending on the direction of the q vector with respect to the polarization. With 0.1 μA on a 2 cm target, one can get a 0.3% asymmetry measurement in one month at 12 GeV for momentum transfers up to 6.5 fm^{-1}. This experiment would take far too long, using many orientations of a horizontal polarization, but a vertical polarization requires out of plane spectrometers.

3 Conclusions

Measurements of polarization observables in elastic *ed* scattering have been of high interest over the past several years. It would be interesting to extend these measurements, and it is possible given sufficient resources. These experiments are difficult at Jefferson Lab, because vector polarizations are small, tensor polarimetry is difficult, with no proven device, and polarized targets cannot operate at high luminosity. The potential increase in count rate with beam energy is balanced by increased kinematic mismatch and the drop in cross section with increasing momentum transfer.

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