Parity Violating Electron Scattering on the Proton and Deuteron at Backward Angles

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Abstract. The parity violating asymmetry in quasielastic electron scattering from the deuteron at backward scattering angles has been recently measured for the first time. Combined with the previously performed similar measurement on the proton, this measurement provides a determination of both the proton's strange magnetic form factor $G'_M$ and the axial vector $e-N$ form factor $G_A^e$. A preliminary analysis indicates that $G'_M$ is slightly positive but consistent with zero and that $G_A^e(T = 1)$ is in substantial disagreement with the theoretical estimate.

INTRODUCTION

The measurement of the neutral weak magnetic form factor of the proton provides an important clue to the quark flavor structure of the nucleon: combined with the known (electromagnetic) magnetic form factors of the proton and neutron, it allows a separation of the proton's magnetic form factor into the three contributing flavors of quarks (up, down and strange) [1]. To the lowest order, the neutral weak magnetic form factor of the proton $G^Z_M$ can be related to the known electromagnetic form factors and a contribution from strange quarks as follows:

$$G^Z_M = (G^p_M - G^n_M) - 4 \sin^2 \theta_W G^p_M - G^s_M,$$

where $G^p_M$ and $G^n_M$ are the electromagnetic magnetic form factors of the proton and neutron, $\theta_W$ is the weak mixing angle, and $G^s_M$ is the contribution from strange quarks. Thus, the measurement of $G^Z_M$ provides unique window to study the role of the strange quark-antiquark "sea" in the electromagnetic structure of the nucleon at low energies.

It is well established that parity violating electron scattering is sensitive to the neutral weak current [2]. Not only is it sensitive to the neutral weak vector current,
but it is also sensitive to the axial current. Unlike the case of $\nu$-$N$ scattering, in $e$-$N$ scattering, the axial form factor $G_A^e$ receives an additional contribution from the anapole form factor and can be written as

$$G_A^e = G_A^Z + \eta F_A + R^e,$$  \hspace{1cm} (2)

where $G_A^Z$ is the contribution from $Z$-exchange, $\eta$ is a constant ($\eta = \tfrac{8\pi}{1-4\sin^2\theta_W} = 3.45$), $F_A$ is the nucleon anapole form factor [3], and $R^e$ is a radiative correction. The anapole form factor is the parity violating coupling of the photon to the nucleon and is generated at the fundamental level from the weak interaction between quarks in the nucleon. Thus, parity violating electron scattering also provides interesting and unique information on the axial vector structure of the nucleon.

At the backward angles, the parity-violating asymmetry for quasielastic scattering on the deuteron for the incident electron energy of 200 MeV can be written as

$$A_d = \left[ \frac{0.049}{\sigma_d} \right] \frac{-G_F Q^2}{\pi \alpha \sqrt{2}} [1 - 0.22G_A^e(T = 1) - 0.10G_M^e].$$  \hspace{1cm} (3)

The similar expression for elastic electron scattering on the proton at 200 MeV is

$$A_p = \left[ \frac{0.026}{\sigma_p} \right] \frac{-G_F Q^2}{\pi \alpha \sqrt{2}} [1 - 0.24G_A^e(T = 1) - 0.61G_M^e].$$  \hspace{1cm} (4)

$G_F$ is the Fermi coupling constant and $\alpha$ is the fine structure constant. $\sigma_d$ and $\sigma_p$ are defined from $\sigma_{(p,n)} = \epsilon(G_B^{(p,n)})^2 + \tau(G_M^{(p,n)})^2$ and $\sigma_d = \sigma_p + \sigma_n$, where $\epsilon$ and $\tau$ are kinematic factors. The asymmetries are given in units of ppm and the form factors in units of nuclear magnetons. Thus, measurement of both $A_p$ and $A_d$ provides a determination of both the strange magnetic form factor $G_A^e(T = 1)$ and the isovector axial form factor $G_A^e(T = 1)$. The contribution from the isoscaler piece of $G_A^e$, although also uncertain, is small.

The measurement of $A_p$ has been already published [4]. Below, we present our new measurement on $A_d$ and the results from preliminary combined analysis of $A_p$ and $A_d$.

**EXPERIMENT AND RESULTS**

The experiment was performed using the SAMPLE apparatus at the MIT/Bates Linear Accelerator Center. The apparatus was essentially the same as in Ref. [4]; the hydrogen target was replaced with liquid deuterium and borated polyethylene shielding was installed between the photomultiplier tubes and the target. This additional shielding was necessary to reduce the background from neutrons produced in the target from $d(\gamma,n)p$ reactions.

A beam of longitudinally polarized electrons was generated from circularly polarized laser light incident on a bulk GaAs crystal, accelerated to 200 MeV, and...
FIGURE 1. A result of a combined analysis of the data from the two SAMPLE measurements. The two error bands from the hydrogen experiment [4] and the preliminary deuterium experiment are indicated. The inner hatched region includes the statistical error and the outer represents the systematic uncertainty added in quadrature. Also plotted is the estimate of the isovector axial $e\cdot N$ form factor $G_A^e(T = 1)$ obtained by using the anapole form factor and radiative corrections of Ref. [5].
then introduced into the deuterium target. The beam was pulsed at 600 Hz and each pulse had a duration of 25 μs. The helicity of the beam was randomly chosen for each of ten consecutive pulses and the complement helicities were used for the next ten pulses. Electrons scattered at backward angles were detected by ten large solid angle air Čerenkov detectors. The asymmetry in the detector signal yield, normalized to incident beam charge, was computed for pulse pairs separated by 1/60 s to minimize systematic errors due to 60 Hz line noise. The measured asymmetry was corrected for the beam polarization (~ 36%) and the background dilution factor to obtain the physics asymmetry.

A result of a combined analysis of the data from the two SAMPLE measurements is shown in Fig. 1. The constraints imposed on the values of $G^*_M$ and $G^*_A(T = 1)$ from the measured values of $A_d$ and $A_p$ using Eqs. (3) and (4) are shown as error bands. The region where the two error bands overlap provides a determination of $G^*_M$ and $G^*_A(T = 1)$. Also plotted in the figure is the estimate of $G^*_A(T = 1)$ obtained by using the anapole form factor and radiative corrections of Zhu et al. [5].

Prior to running these experiments, the expected value of $G^*_M$ was in the range of −0.5 to 0 [6], and the expected value of $G^*_A$ was $\sim −0.71 \pm 0.20$ as a result of substantial modification due to the anapole term and the radiative correction [7] (their recent update in Ref. [5] gives a consistent value). The experiments indicate a rather different picture as shown in Fig. 1. The best value of $G^*_M$ appears to be slightly positive, consistent with zero, and the best value of $G^*_A$ indicates that the substantial modifications of $G^*_A$ predicted in Refs. [7,5] are not only present, but probably with an even larger magnitude. From a theoretical standpoint, the most uncertain contribution to $G^*_A$ is from the anapole term and the experimental results can be interpreted as an unexpectedly large anapole form factor of the nucleon.

Clearly the situation warrants further theoretical study as well as additional experimental investigation. It is expected that a new measurement of parity violating quasielastic electron-deuteron scattering at lower energy [8] will provide an improved determination of $G^*_A(T = 1)$ as well as $G^*_M$.

REFERENCES