ISSN 1330–0016
CODEN FIZBE7

LETTER TO THE EDITOR

MEASUREMENT OF RECOIL POLARIZATION IN THE $^{16}O(\vec{e}, e'\vec{p})$ REACTION

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Received 29 January 1999; Accepted 7 July 1999

The longitudinal and transverse components of the polarization of the outgoing proton were measured for the reaction $^{16}O(\vec{e}, e'\vec{p})$ at a four-momentum transfer squared of 0.8 GeV^2 in quasifree kinematics. These were the first measurements of polarization transfer observables for a complex nucleus. Comparison of the ratio of the transverse and longitudinal polarization to theoretical predictions allows the study of modification of the proton's form factors in the nuclear medium.

PACS numbers: 13.40.Gp, 14.20.Dh, 25.30.Fj UDC 539.125, 539.14

Keywords: electric and magnetic form factors of proton, modification in nuclear medium, $^{16}O(\vec{e}, e'\vec{p})$ reaction, quasifree kinematics, longitudinal and transverse polarization of outgoing proton

Interest in studying possible modifications of the structure of the nucleon in nuclear matter has been longstanding. Previous investigations of medium modifications of the ratio of the electromagnetic form factors of the proton have focused on cross section measurements [1,2]. Since measurements at different kinematic settings are needed to separate the longitudinal and transverse observables, systematic errors can be large. The theoretical interpretation of cross section data is also significantly model-dependent. With the advent of high polarization, high current, continuous beam facilities like the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory, measurements of polarization transfer observables from scattering on heavy nuclei have become feasible. Systematic errors in the measurement of the ratio of polarization observables are small. In addition, calculations indicate that final state interactions, choice of gauge, and other such uncertainties in the interpretation of the reaction have only a small effect on this ratio [3], so that the effect of medium modification of the proton's form factor can be isolated. Effects of isobar excitation and meson exchange currents, which can also modify the predicted polarization transfer observables [4], are expected to be small in the ratio, but further study is needed. Recent predictions of the expected medium modifications based on the quark-meson coupling model [5] suggest that the ratio of the proton's electric form factor, G_E, to its magnetic form factor, G_M, in ^{16}O would be lower than the free value by about 10-15% at a Q^2 of 0.8 GeV^2.

Experiment 89-033, described here, was the first to use the polarized beam and the focal plane polarimeter (FPP) in Hall A at Jefferson Lab. The initial checks of the FPP were based on measurement of G_E/G_M for the ^{1}H($\vec{e}$, e$'\vec{p}$) reaction. At $Q^2 = 0.8$ GeV^2, $\mu G_E/G_M$ is known from Rosenbluth's separation data [6,7] (μ is the magnetic moment of the proton). For $\vec{e}$p elastic scattering, the longitudinal, P_l, and transverse, P_t, polarization transfer observables can be written in terms of G_E/G_M and kinematic factors in the one-photon-exchange approximation. Therefore, a simultaneous measurement of P_l and P_t allows one to determine

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{(E_e + E_e')}{2M}\tan(\frac{\theta_e}{2}), \tag{1}$$

where E_e is the beam energy, E_e' is the scattered electron's energy, M is the proton's mass and θ_e is the angle of scattered electron [8].

The longitudinal and transverse components of the proton polarization at the target are not measured directly; they must be extracted from the polarizations measured at the focal plane of the (vertical) spectrometer. The proton's magnetic moment precesses in the magnetic field of the spectrometer which leads to a mixing of the target polarizations at the focal plane. The mixing can be represented by a spin matrix with nine elements and the relationship between the target- and focal-plane polarizations is given by:

$$\begin{pmatrix} P_{n'}^{fp} \\ P_{t'}^{fp} \\ P_{l'}^{fp} \end{pmatrix} = \begin{pmatrix} S_{n'n} & S_{n't} & S_{n'l} \\ S_{t'n} & S_{t't} & S_{t'l} \\ S_{l'n} & S_{l't} & S_{l'l} \end{pmatrix} \begin{pmatrix} P_n \\ hP_t \\ hP_l \end{pmatrix}, \tag{2}$$

where h is the beam helicity and the fp superscript indicates a focal plane polarization. The spin matrix depends on the angle of scattered proton, momentum and position relative to the central values of the spectrometer. For a simple dipole magnet, with the magnetic field in the transverse (sideways) direction, the transverse (sideways) polarization does not change. The longitudinal and normal polarization rotate about the transverse axis and at the focal plane have the following values:

$$P_{n'}^{fp} = P_n\cos(\chi) + hP_l\sin(\chi) \text{ and } P_{t'}^{fp} = hP_t, \tag{3}$$

where χ is the precession angle. The fact that P_n is an induced polarization can be used to separate P_n from the helicity-dependent P_l in $P_{n'}^{fp}$. For hydrogen, $P_n = 0$ in the one-photon-exchange approximation.

The FPP consists of two front straw-tube drift chambers which determine the proton's track incident onto the carbon analyzer and two rear straw-tube drift chambers which determine the track of the scattered proton. The normal, $P_{\rm n'}^{\rm fp}$, and transverse, $P_{\rm t'}^{\rm fp}$, polarizations are extracted from a measurement of the angular distributions as a function of the azimuthal scattering angle, ϕ, in bins of the polar scattering angle, θ :

$$I(\phi, \theta) = I_o(\theta)[1 - A(\theta)P_{\rm n'}^{\rm fp}\cos(\phi) + A(\theta)P_{\rm t'}^{\rm fp}\sin(\phi)] \,. \qquad (4)$$

$A(\theta)$ is the analyzing power of carbon; it can be taken from previous measurements or determined on-site as part of the hydrogen measurement. The helicity of the beam was flipped at a rate of 30 Hz, and angular distributions $I^+(\phi, \theta)$ and $I^-(\phi, \theta)$ were measured for the two helicity states. Then a Fourier analysis of $I^+(\phi, \theta) - I^-(\phi, \theta)$ was done to extract $P_{\rm n}^{\rm fp}$ and $P_{\rm t}^{\rm fp}$. For a hydrogen target, the sum, $I^+(\phi, \theta) + I^-(\phi, \theta)$, eliminates the helicity-dependent parts of the distribution, and the Fourier analysis reveals the instrumental asymmetries.

The experiment was done at a beam energy of 2.445 GeV and used a waterfall target which consisted of three foils. The electron spectrometer was set at 23.4° for all measurements. The proton spectrometer was set at -53.3°,-55.7°, -60.5° and -50.8° which correspond to a central missing momentum, p_m, of 0, 85, 140, and -85 MeV/c, respectively. The reaction ^{1}H($\vec{\rm e}$, e$'\vec{\rm p}$) was in the spectrometer's acceptance at both p_m of 0 and 85 MeV/c. Having two kinematic settings to measure the hydrogen polarizations gave an opportunity to test the understanding of the optics of the proton spectrometer, since the phase space occupied by the elastic events is different in the two settings. The hydrogen elastic events were separated from the oxygen events using a two-dimensional cut on the missing energy versus missing momentum. With the cut on hydrogen events, the distributions for the horizontal angle relative to the central angle ($\phi_{\rm tgt}$) and position ($y_{\rm tgt}$) at the target are plotted in Fig. 1 for the two kinematic settings. In the $p_m = 0$ kinematics, all three waterfall targets are visible, though the center waterfall is not at zero due to mispointing of the spectrometer. The distribution about $\phi_{\rm tgt} = 0$ is fairly symmetric, but again the mispointing slightly distorts the distribution. For the $p_m = 85$ MeV/c kinematics, the proton spectrometer was moved by 2.4° and one sees that only elastic hydrogen events with positive $\phi_{\rm tgt}$ made it into the spectrometer acceptance. This meant that only two waterfall foils were visible. Using the full spin matrix, $\mu G_{\rm E}/G_{\rm M}$ measured at $p_m = 0$ and 85 MeV/c agree with one another and are in good agreement with the previous measurement of $\mu{\rm G_E/G_M} = 0.945 \pm 0.03$ [6,7]. This demonstrates that spin transport in the proton spectrometer is well understood.

With confidence in the measurements for the hydrogen data, the $P_{\rm l}$ and $P_{\rm t}$ can be measured for the ^{16}O($\vec{\rm e}$, e$'\vec{\rm p}$)^{15}N reaction. For a proton in the nucleus, there is no simple formula relating $G_{\rm E}/G_{\rm M}$ and $P_{\rm t}/P_{\rm l}$. Instead, one needs to calculate $P_{\rm t}/P_{\rm l}$ from theory and compare to the data. The linear expansion analysis (LEA) code of J. Kelly [3] was used to calculate the ratio $P_{\rm t}/P_{\rm l}$ using the free proton form factors. One would expect the ratio $(P_{\rm t}/P_{\rm l})_{exp}/(P_{\rm t}/P_{\rm l})_{theory}$ to be unity if the form factors of the proton are unmodified in ^{16}O and other effects are negligible. Preliminary analysis of the data, summed over the three dominant 1/2-, 3/2-, and 1/2+ states, yields a ratio $(P_{\rm t}/P_{\rm l})_{exp}/(P_{\rm t}/P_{\rm l})_{theory}$ consistent with unity within about 10%. This initial measurement thus seems to rule out a large effect on the proton form factors in ^{16}O at this momentum transfer, but much better statistics will be needed to see the 10-15% effects predicted in Ref. 5.

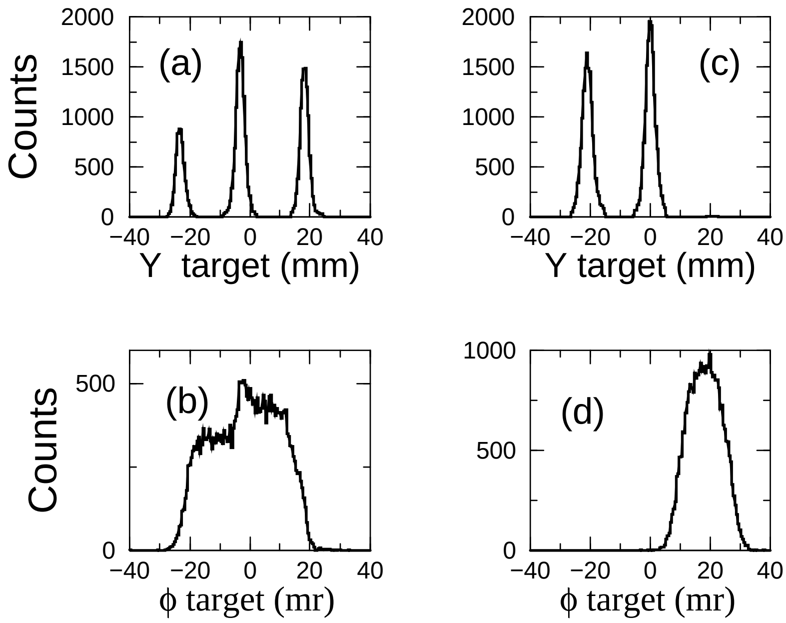

Fig. 1. The reconstructed distributions of $y_{\rm tgt}$ and $\phi_{\rm tgt}$ for the ^{1}H(e,e′p) *reaction a) and b) at p_m = 0* MeV/*c*, *and c) and d) at p_m = 85* MeV/*c*.

Since this experiment was carried out in the summer of 1997, changes in the polarized source at Jefferson Lab have dramatically improved the quality of the polarized beam, so that subsequent polarized beam experiments have yielded much better data. The calculations of Ref. 5 predict that the medium effects on $G_{\rm E}/G_{\rm M}$ are larger at higher Q^2 and have little dependence on the mass of the nucleus. The next such measurement scheduled at Jefferson Lab will explore a large range of Q^2 in the ^{4}He($\vec{\rm e}$, e′$\vec{\rm p}$) reaction. It is expected to be sensitive to modification of $G_{\rm E}/G_{\rm M}$ in the nuclear medium at the 3–5% level [9].

Acknowledgements

We would like to thank the Jefferson Lab accelerator and Hall A staff for their support during this experiment. Results presented here are the thesis work of Krishni Wijesooriya (College of William and Mary) and Sergey Malov (Rutgers University). This work is supported in part by the U.S. National Science Foundation and the U.S. Department of Energy.

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MJERENJE ODBOJNE POLARIZACIJE U REAKCIJI $^{16}O(\vec{e}, e'\vec{p})$

Mjerile su se uzdužna i poprečna komponenta polarizacije izlaznih protona u reakciji $^{16}O(\vec{e}, e'\vec{p})$ za kvadrat prijenosa impulsa od 0.8 GeV^2, u kvazislobodnim kinematičkim uvjetima. Ovo su prva mjerenja prijenosa polarizacije za složenu jezgru. Usporedba omjera poprečne i uzdužne polarizacije s teorijskim predviđanjima omogućava proučavanje promjena faktora oblika protona kada je u nuklearnom okruženju.