ISSN 1330–0016
CODEN FIZBE7

LETTER TO THE EDITOR

RECOIL POLARIZATION IN ELECTROPRODUCTION OF MESONS

JAMES J. KELLY

Department of Physics, University of Maryland, College Park, MD 20742, U. S. A.

Received 2.February 1999; Accepted 7 June 1999

We briefly review the objectives and techniques for several experiments upon recoil polarization in electroproduction of pseudoscalar mesons that will be performed in Hall A at Jefferson Laboratory.

PACS numbers: 13.60.Le, 13.88.+e, 14.20.Gk UDC 539.126

Keywords: meson electroproduction, nucleon resonances, recoil polarization, superparallel kinematics

Transition form factors for the electroexcitation of nucleon resonances provide stimulating tests of QCD-inspired models of baryon structure. The experimental program now underway in Hall B at Jefferson Laboratory (JLab) will soon provide cross-section data whose statistical precision and coverage of phase space will greatly exceed the world's extant data set. However, it is difficult to separate the form factors for overlapping resonances that interfere with each other and with nonresonant background using only cross-section data. Minimization of ambiguities in multipole analysis requires both target and recoil polarization data. Target-polarization data will be acquired in Hall B while recoil polarization will be obtained in Hall A. In this contribution, we highlight some of the unique sensitivities offered by recoil polarization, with particular emphasis upon a new method for measuring longitudinal amplitudes using recoil polarization instead of Rosenbluth separation.

It is usually very difficult to measure the longitudinal response function, R_{L}, without substantial systematic errors using the traditional Rosenbluth method because unpolarized cross sections for meson electroproduction are usually dominated by the transverse response function, R_{T}. Consequently, there exist few data for longitudinal excitation with useful accuracy. Yet, it is very important to obtain accurate measurements of the longitudinal form factors for baryon electroexcitation because these quantities are quite sensitive to configuration mixing in quark models and to relativistic corrections.

It can be shown (e.g. Refs. 1 and 2) that recoil polarization observables for parallel kinematics reduce to

$$\begin{aligned} \widetilde{\sigma}_0 &= \nu_{\rm L}\, R_{\rm L} + \nu_{\rm T}\, R_{\rm T} \\ \widetilde{\sigma}_0 \Pi_{\rm N} &= \nu_{\rm LT}\, R_{\rm LT}^{N} \\ \widetilde{\sigma}_0 \Pi_{\rm S} &= h\nu'_{\rm LT}\, R_{\rm LT}^{\prime S} \\ \widetilde{\sigma}_0 \Pi_{\rm L} &= h\nu'_{\rm TT}\, R_{\rm TT}^{\prime L}\,, \end{aligned}$$

where $\widetilde{\sigma}_0$ is an unpolarized reduced cross section, $\mathbf{\Pi} = \mathbf{P} + h\mathbf{P}'$ is the net polarization containing a helicity-independent part, $\mathbf{P}$, and a helicity-dependent part, $\mathbf{P}'$. The kinematic coefficients, ν_α, depend only on electron scattering kinematics, while the corresponding response functions, R_α, containing the dynamical content of the reaction, depend upon invariant mass, W, photon virtuality, Q^2, and the center-of-mass, angle $\theta_{\rm N}$, between the ejected nucleon and the virtual photon. We employ a basis in which $\hat{L}$ is along the nucleon recoil momentum and $\hat{N}$ is normal to the reaction plane containing the nucleon and meson momenta. A more detailed accounting of the response functions and notation can be found in Refs. 1 and 2.

The reaction amplitudes for any A(e,e$'$ N)B process, where A has spin $\frac{1}{2}$ and B spin 0 that is governed by the one-photon exchange mechanism, can be expressed in terms of helicity amplitudes of the form

$$H_{\lambda_f \lambda_i \lambda_\gamma}(Q^2, W, \theta_{\rm N}, \phi_{\rm N}) = \langle \lambda_f | \mathcal{F}_\mu \varepsilon^\mu | \lambda_i, \lambda_\gamma \rangle\,,$$

where λ_i and λ_f are the initial and final helicities of the nucleon, λ_γ is the helicity of the virtual photon, $\mathcal{F}^\mu$ is an appropriately normalized transition current operator, and ε^μ is the virtual-photon polarization. Since parity conservation requires

$$|H_{-\lambda_f - \lambda_i - \lambda_\gamma}| = |H_{\lambda_f \lambda_i \lambda_\gamma}|\,,$$

it is sufficient [3,4] to consider the six independent amplitudes

$$\begin{aligned} H_1 &= \langle -\tfrac{1}{2} | \mathcal{F}_\mu \varepsilon^\mu | -\tfrac{1}{2}, 1\rangle & H_4 &= \langle +\tfrac{1}{2} | \mathcal{F}_\mu \varepsilon^\mu | +\tfrac{1}{2}, 1\rangle \\ H_2 &= \langle -\tfrac{1}{2} | \mathcal{F}_\mu \varepsilon^\mu | +\tfrac{1}{2}, 1\rangle & H_5 &= \langle +\tfrac{1}{2} | \mathcal{F}_\mu \varepsilon^\mu | +\tfrac{1}{2}, 0\rangle \\ H_3 &= \langle +\tfrac{1}{2} | \mathcal{F}_\mu \varepsilon^\mu | -\tfrac{1}{2}, 1\rangle & H_6 &= \langle +\tfrac{1}{2} | \mathcal{F}_\mu \varepsilon^\mu | -\tfrac{1}{2}, 0\rangle\,. \end{aligned}$$

Due to the absence of orbital angular momentum in the initial state or spin in the undetected recoil particle (B), the angular momentum projected onto the virtual photon direction reduces to $J_z = \lambda_\gamma - \lambda_i = \pm\lambda_f$ for parallel (+ sign) or antiparallel (- sign) kinematics. Hence, only H_4 and H_6 contribute to parallel or H_2 and H_5 to antiparallel kinematics.

With only two complex helicity amplitudes surviving in parallel kinematics, there can be only four independent response functions. For recoil polarization, one obtains the following relationships (very similar results are obtained for target polarization):

Response function	Parallel	Antiparallel
R_{L}	$\vert H_6\vert^2$	$\vert H_5\vert^2$
R_{T}	$\frac{1}{2}\vert H_4\vert^2$	$\frac{1}{2}\vert H_2\vert^2$
R'^{L}_{TT}	$\frac{1}{2}\vert H_4\vert^2$	$-\frac{1}{2}\vert H_2\vert^2$
R'^{S}_{LT}	$-\frac{1}{\sqrt{2}}\mathrm{Re}H_4H_6^*$	$-\frac{1}{\sqrt{2}}\mathrm{Re}H_2H_5^*$
R^{N}_{LT}	$\frac{1}{\sqrt{2}}\mathrm{Im}H_4H_6^*$	$-\frac{1}{\sqrt{2}}\mathrm{Im}H_2H_5^*$

Thus, it is possible to obtain both the magnitudes and the relative phases of the H_4 and H_6 helicity amplitudes in parallel kinematics or the H_2 and H_5 amplitudes in antiparallel kinematics using either recoil or target polarization measurements.

The symmetry property $R'^{\mathrm{L}}_{\mathrm{TT}} = \pm R_{\mathrm{T}}$, with upper (lower) sign for parallel (antiparallel) kinematics, can be used to separate R_{L} and R_{T} using recoil polarization measurements with fixed electron-scattering kinematics. We define

$$\mathcal{R}_{\pm}(Q^2,W) = \left.\frac{R_{\mathrm{L}}(Q^2,W,\theta_{\mathrm{N}})}{R_{\mathrm{T}}(Q^2,W,\theta_{\mathrm{N}})}\right|_{\theta_{\mathrm{N}}=0,\pi} = \frac{\pm h\nu'_{\mathrm{TT}} - \nu_{\mathrm{T}}\,\Pi_{\mathrm{L}}}{\nu_{\mathrm{L}}\,\Pi_{\mathrm{L}}}$$

as the ratio between the longitudinal- and transverse-response functions for parallel (antiparallel) kinematics and find that this ratio depends upon the nucleon polarization, Π_{L}, parallel to both the momentum transfer and the ejectile momentum. We refer to these conditions as *superparallel kinematics*. This technique avoids the major systematic errors involved in the Rosenbluth method, which tend to be large because acceptances and cross sections vary rapidly with electron-scattering angle. Furthermore, it is important to recognize that the underlying symmetry property for pseudoscalar meson production is quite general, requiring only one-photon exchange and parity conservation – it does not depend upon dominance of a particular resonance and applies equally well to the resonant and nonresonant contributions. However, it need not apply to more complicated background processes such as p(e,e′N) $\pi\pi$. Fortunately, those contributions should vary slowly with missing mass and can be subtracted when the meson is narrow. Nor can this technique be used to obtain full angular distribution for R_{T} and R_{L} without Rosenbluth separation.

We have proposed to measure the angular distributions for recoil polarization in the $\mathrm{p}(\vec{\mathrm{e}},\mathrm{e}'\vec{\mathrm{p}})\eta$ reaction near the $\mathrm{S}_{11}(1535)$ resonance at $Q^2 = 0.5$ $(\mathrm{GeV}/c)^2$ [2]. Although it is well known that the $\mathrm{S}_{11}(1535)$ resonance dominates η electroproduction, nondominant resonance and nonresonant background still complicate accurate extraction of its electroexcitation form factors. The sensitivities of coplanar response functions to selected nondominant resonances were examined in some detail in Ref. 2. We find that the $R'^{\mathrm{S}}_{\mathrm{TT}}$ response function provides the most robust signal for the $|E_{0+}|^2$ multipole amplitude – the calculation using only S_{11} and nonresonant amplitudes is practically identical with the full calculation including many additional resonances. By contrast, the substantial contribution to R_{T} from poorly known $\mathrm{P}_{11}(1440)$ amplitudes would make it difficult to isolate E_{0+} without using polarization. It is also worth noting that the $\mathrm{D}_{13}(1520)$ resonance dominates R_{LT}. Finally, although R_{L} is expected to be small, $\mathcal{R}_{\pm}$ can still be obtained with good precision using the recoil-polarization technique for superparallel kinematics. Experiment 96-001 requires approximately 75μA of 75% polarized beam and will request scheduling when this combination of beam parameters is achieved.

Quadrupole amplitudes for the N $\to \Delta$ transition are sensitive to deformation induced by color hyperfine interactions and are the subject of many current experimental and theoretical investigations. Although recent photoexcitation experiments have provided reliable, if slightly model-dependent, values of E_{1+} at $Q^2 = 0$, form factors and scalar amplitudes require electroexcitation. The $R_{\rm LT}$ response function is quite sensitive to the S_{1+} amplitude, but background contributions are not negligible. Recent measurements suggest values of ${\rm Re}S_{1+}M^*_{1+}/|M_{1+}|^2 \approx -12\%$ [5,6]. However, Kalleicher et al. [5] omitted the nonresonant background while a recent measurement of $P_{\rm N}$ [7] at the same $Q^2 = 0.13$ (GeV/c)^2 suggests that scalar background amplitudes are substantially larger than predicted by current models and are not negligible. Thus, in order to reduce the model dependence of S_{1+} measurements, it becomes important to understand better the background amplitudes. The helicity-independent recoil-polarization response functions depend upon the imaginary parts of interference products, ${\rm Im}ab^*$, which emphasize the role of nonresonant background. Experiment 91-011 [8] will measure both helicity-dependent and helicity-independent coplanar response functions for pion electroproduction at the Δ resonance for $Q^2 = 1.0$ (GeV/c)^2. It is expected that a multipole analysis of these data will provide S_{1+} with little model dependence and will better characterize the properties of the nonresonant background.

We conclude that recoil polarization provides some unique opportunities for studying baryon electroexcitation and plan to develop additional experimental proposals as the required techniques mature.

References

1) J. J. Kelly, Adv. Nucl. Phys. **23** (1996) 75;
2) J. J. Kelly et al., *Recoil Polarization in η Electroproduction*, TJNAF Proposal 96-001 (1996);
3) H. F. Jones, Il Nuovo Cimento **40** (1965) 1018;
4) R. L. Walker, Phys. Rev. **182** (1969) 1729;
5) F. Kalleicher, U. Dittmayer, R. W. Gothe, H. Putsche, T. Reichelt, B. Schoch and M. Wilhelm, Z. Phys. A **359** (1997) 201;
6) V. V. Frolov et al., Phys. Rev. Letters **82** (1994) 45;
7) G. A. Warren et al., Phys. Rev. C **58** (1998) 3722;
8) R. W. Lourie et al., *Investigation of the* N$\to \Delta$ *Transition via Polarization Observables in Hall A*, TJNAF Proposal 91-011 (1991).

ODBOJNA POLARIZACIJA U ELEKTRO-TVORBI MEZONA

Daje se pregled ciljeva i metoda više mjerenja odbojne polarizacije u elektro-tvorbi pseudoskalarnih mezona koja će se izvoditi u hali A Jeffersonovog Laboratorija.