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MEASUREMENT OF THE POLARIZATION
IN ELASTIC ELECTRON-PROTON SCATTERING*

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ABSTRACT

We have measured the asymmetry in the elastic scattering of electrons from a polarized proton target. An interference between the imaginary part of the two-photon-exchange amplitude and the real photon-exchange amplitude produced a polarization effect. The results indicate no asymmetry within the experimental accuracy of 1 to 2% at four-momentum transfer squared values of 0.38, 0.57 and 0.98 (GeV/c)².

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The customary reliance on one-photon-exchange calculations in electron-proton scattering makes it important to study those processes which could only arise from higher-order effects. A measurement of nonzero proton polarization in elastic electron-proton scattering would be evidence for a two-photon-exchange amplitude, since the polarization must vanish for pure one-photon exchange. The interference between one-photon-exchange and two-photon-exchange amplitudes is expected to be smaller than the one-photon-exchange contribution by an order of α , but it may be enhanced due to the presence of some resonance process.¹

In electron-proton elastic scattering, one-photon exchange leads to the Rosenbluth formula² for the differential cross section. Higher-order effects, which could show up as deviations from the Rosenbluth form, have not been observed so far.³

The interference between the one-photon amplitude and the real part of some two-photon amplitudes can be obtained by comparing electron-proton and positron-proton elastic scattering. These measurements⁴ (after allowing for radiative losses⁵) have shown no evidence of two-photon effects, to an accuracy of about the order α , up to four-momentum transfers squared of 5.0 (GeV/c)^2 .

Information relating to the imaginary part of a different combination of two-photon-exchange amplitudes can be measured by performing a polarization experiment. Two kinds of experiments are possible. One can measure the polarization, P , of the recoiling nucleon in the elastic scattering of unpolarized electrons from an unpolarized proton target. Alternatively (as in the present experiment) one can measure the asymmetry, A , in the scattering of electrons from a polarized proton target.

defined as

$$A = \frac{\sigma_{\parallel} - \sigma_{\perp}}{\sigma_{\parallel} + \sigma_{\perp}} = \frac{\epsilon}{|P_T| H_F} \quad (1)$$

where σ_{\parallel} , σ_{\perp} denote the cross sections on hydrogen polarized parallel and anti-parallel to the normal (\hat{n}) to the electron scattering plane. The quantity ϵ is the asymmetry in the raw counts from the polarized target, and the factors P_T , H_F allow for the target proton polarization and the fraction of hydrogen counts present in the data, respectively. We define \hat{n} , as:

$$\hat{n} = \frac{\vec{p}_{in} \times \vec{p}_{out}}{|\vec{p}_{in} \times \vec{p}_{out}|} \quad (2)$$

where \vec{p}_{in} and \vec{p}_{out} are the momenta of the initial and final electron, respectively.

The asymmetry, A , is related to the polarization P . If only one photon is exchanged, then $A = P = 0$ because hermiticity and current conservation combine to prohibit any polarization of the recoil proton, or, equivalently, any dependence of the cross section on the initial proton spin direction.⁶ If T-invariance holds, then $A = P$ to all orders in the electromagnetic interaction. Four values of P have been reported⁷ over the four-momentum transfer range from 0.3 to 0.8 (GeV/c)², and are consistent with $P = 0$. Several theoretical attempts⁸ have been made to estimate the order of magnitude of the polarization due to the two-photon terms, and the predictions tend to be less than 1%.

Incident electron beams of 15 and 18 GeV from the Stanford Linear Accelerator were focused onto a polarized butanol target. The electrons which elastically scattered from the target were momentum selected using the 20-GeV/c magnetic spectrometer and detected in a ten-scintillation-counter hodoscope. For one momentum setting of the spectrometer, the hodoscope covered a missing-mass range of approximately ± 200 MeV about the elastic electron-proton scattering

peak. Each hodoscope counter subtended about 60 MeV in missing mass. The elastic data were taken from a sum of the three missing-mass bins which centered around the kinematics for elastic electron-proton scattering. Some runs were made with the elastic peak positioned near one side of the hodoscope, while others were made with the elastic peak centered on the hodoscope. Electrons were detected by observing the pulse-height in a total-absorption lead-scintillator shower counter. An upper limit of 0.2% can be placed upon the pion contamination in the data. The experimental details and method of analysis of this measurement were the same as those given in the preceding Letter.⁹ The procedure for data-taking involved reversing the sign of the target polarization once every three minutes and recording the number of counts per unit beam-current monitor. As the spin reversal was effected by applying only a small change in the frequency of the microwave power to the target, with all other conditions remaining fixed, systematic errors tended to cancel. In all, about 15 million events were obtained in the elastic region. As seen in Eq. (1), the measured asymmetry ϵ is diluted by the target polarization (P_T was about 0.20) and the fraction of counts due to hydrogen in the target (H_T was about 0.20). Because of this dilution, a 0.04% asymmetry in raw counts (ϵ) becomes a 1% asymmetry in A .

Errors can arise from: (1) lack of knowledge of the target polarization, (2) uncertainty in the determination of the hydrogen fraction, (3) monitoring errors, (4) statistical error in the total counts, and (5) other systematic effects.

The measurement of the target polarization employed standard NMR techniques.¹⁰ Recent improvements¹¹ led us to believe that the polarization was known to within 5% ($= \Delta P_T / P_T$).

The hydrogen fraction, H_F , was determined as a function of missing mass as follows:

1. Data were taken at the kinematics corresponding to elastic electron-proton scattering using butanol, carbon and polyethylene (CH_2) targets. A pure hydrogen spectrum was obtained from a $CH_2 - C$ subtraction, and the butanol spectrum was fitted by a linear combination of this hydrogen spectrum and the carbon spectrum. The prominence of the elastic peak from hydrogen improved the accuracy of the fit to the butanol spectrum.
2. Spectra were taken at all kinematic conditions, both elastic and inelastic, using C and CH_2 targets. A second $CH_2 - C$ subtraction was effected, and the ratio of carbon scattering to hydrogen scattering for CH_2 was calculated for each missing-mass bin. Finally, this ratio was normalized to the butanol target using the fitting parameters obtained in step (1).

The quantity H_F was thus determined to about 20% of its value. However, since H_F is a normalizing factor, its error does not seriously affect the results. In Fig. 1, we show the measured spectrum obtained by scattering 15 GeV electrons from the butanol target together with a spectrum for pure hydrogen which was calculated by the above procedure.

The asymmetry, A , was calculated separately for each of the three different beam-current monitors which were used in the experiment. These asymmetries agreed with one another to within one-fifth the size of the statistical errors. The monitor errors, therefore, can be neglected. From the study of "test" asymmetry values (see Ref. 9 for the details) we believe that our systematic errors are small, and that the uncertainty in the measurement can be represented by the errors calculated from counting statistics.

The final asymmetry values at three values of four-momentum transfer squared (q^2) are shown in Table I, where the errors in A are calculated from counting statistics only, which are believed to be close to the total errors. Within the measurement errors, the values are consistent with $A=0$. These results are compared with the previous measurements⁷ of P in Fig. 2.

From the results of this experiment and from the measurements of Mar et al.,⁴ on the real part of two-photon exchange, one can conclude that the higher-order contributions to elastic electron-proton scattering have been found to lie between 0 and order α , in agreement with the theoretical estimates.^{1,8}

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$$P = (-0.006 \pm 0.020) \text{ measured at } q^2 = 0.27 \text{ (GeV/c)}^2$$

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TABLE I

Asymmetry values, A , for the elastic scattering of electrons from a polarized proton target. The errors have been calculated from counting statistics which we believe represent the total errors.

Incident electron energy GeV	Electron scattering angle (deg)	Four-momentum transfer squared (GeV/c) ²	Number of elastic events ($\times 10^6$)	Hydrogen fraction H_F	Asymmetry A
15.0	2.37	0.38	1.8	0.20	-0.004 ± 0.014
18.0	2.48	0.59	11.6	0.16	-0.005 ± 0.009
18.0	3.21	0.98	1.5	0.21	-0.003 ± 0.018

FIGURE CAPTIONS

1. The measured spectrum for scattering 15 GeV electrons (at 2.37° lab) from the polarized butanol target and a calculated spectrum for scattering from the pure hydrogen in the target ($=H_p \times$ butanol spectrum).
2. The asymmetry measurements for elastic electron-proton scattering are shown versus four-momentum transfer squared. This experiment measured the asymmetry for scattering electrons from a polarized proton target. The other values (Ref. 7) were from analyzing the polarization of the protons recoiling from an unpolarized proton target. We have changed the sign of the latter data to be consistent with the definition of \hat{n} given in Eq. (2) of this paper.

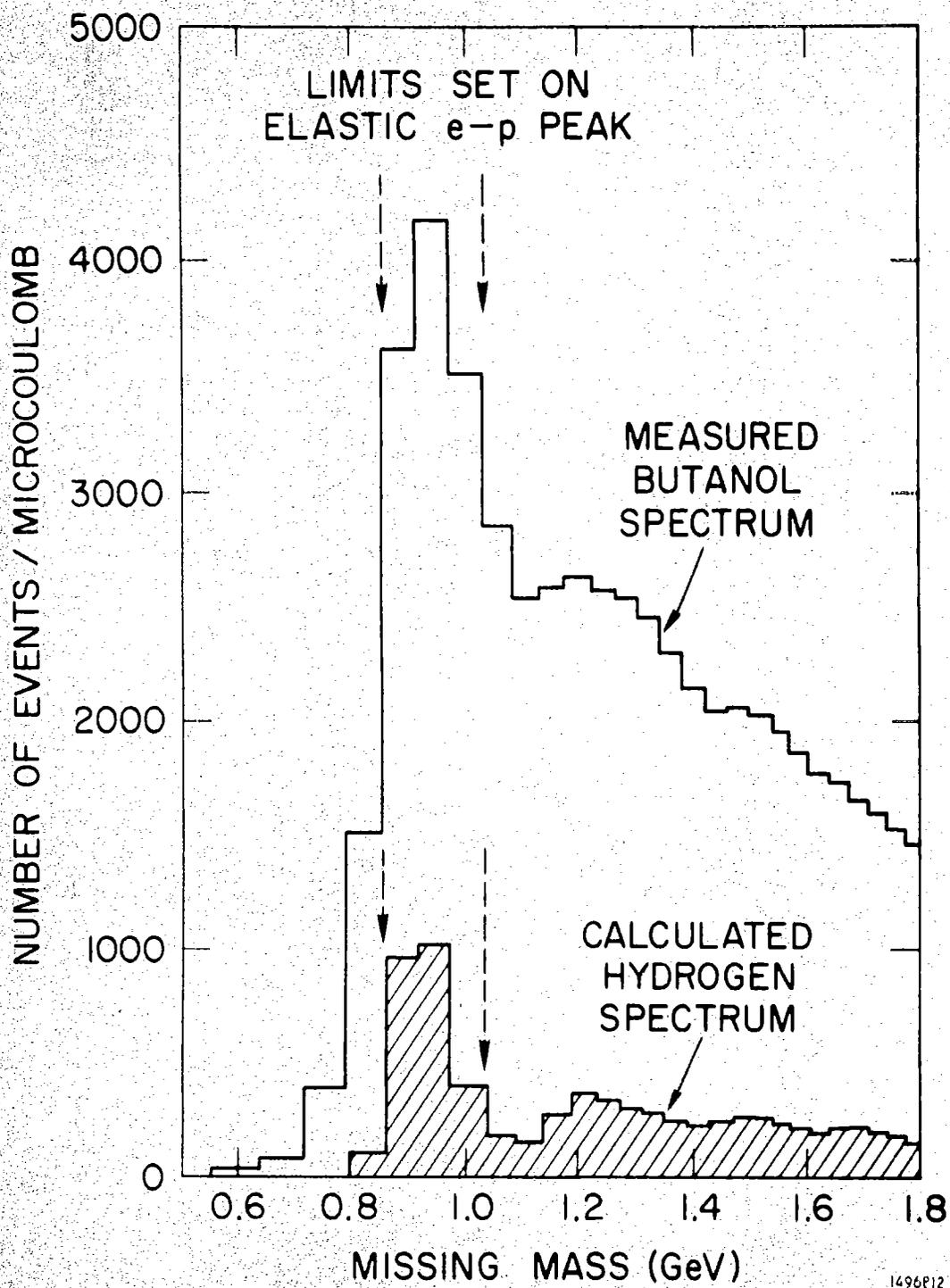
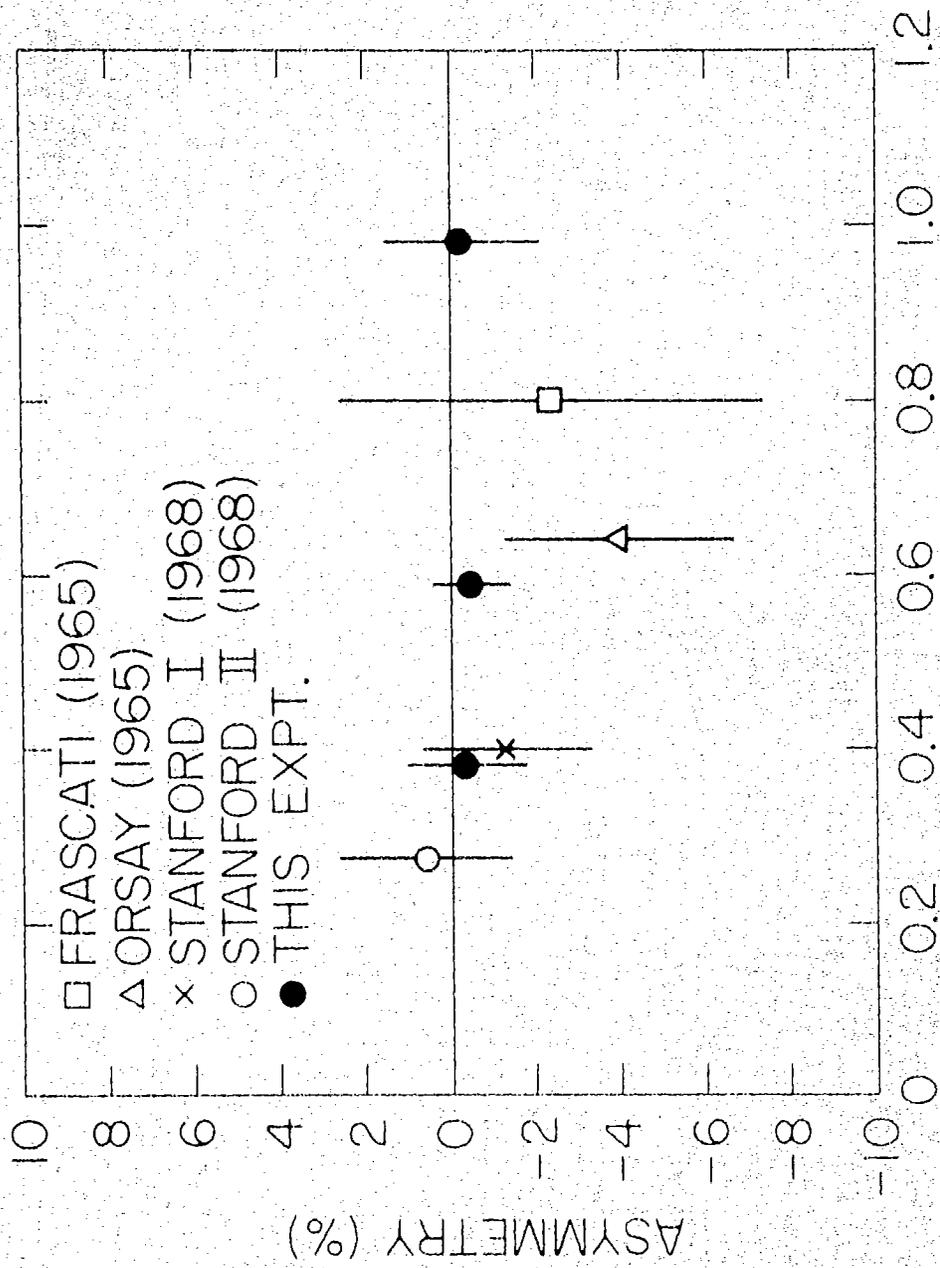


Fig. 1



FOUR-MOMENTUM TRANSFER SQUARED (GeV/c)²

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Fig. 2