# ELECTRON SCATTERING FROM THE PROTON*

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We have recently put into operation a new large double-focusing magnetic spectrometer capable of analyzing electrons or other singly-charged particles up to a momentum value of 1000 Mev/$c$. This spectrometer is of the 180° type previously used in this laboratory and has a mean radius of curvature of 72 in. We have employed this spectrometer in electron-scattering work on the proton between incident electron energies of 650 Mev and 900 Mev and between scattering angles of 45° and 145°. A typical value of the solid angle employed in detecting electrons is $5.6\times10^{-3}$ steradian. The higher energies (>650 Mev) have been realized by virtue of the recent extension in the length of the Stanford linear accelerator.

The 72-in. spectrometer forms part of a two-magnet system; the second part is the 36-in. spectrometer described previously.[1] Figure 1 is a schematic drawing of the two spectrometers in a position in which they are 120° apart. Both spectrometers are arranged so that they can be rotated independently about a common scattering center. We have taken data simultaneously with both spectrometers, usually employing the 36-in. magnet at large angles, e.g., up to 145°. The 36-in. spectrometer can handle scattered electrons only up to 500 Mev/$c$ without excessive deterioration of focusing and we have used the 36-in. spectrometer in these experiments only in the very safe region below 370 Mev/$c$. Such a procedure limits, and has limited in the past, the ability of this spectrometer in obtaining scattering data at high energies and small angles,[1,2] i.e., in those circumstances where the energy of the scattered electron is high.

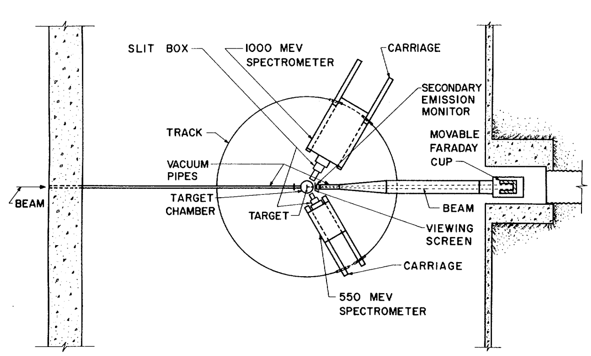


FIG. 1. The double spectrometer system used in these experiments.

We have begun to carry out a series of experiments on the proton at various energies and angles with these spectrometers. In both instruments we used Čerenkov counters as detectors. In. Fig. 2(a) we show a typical electron-scattering

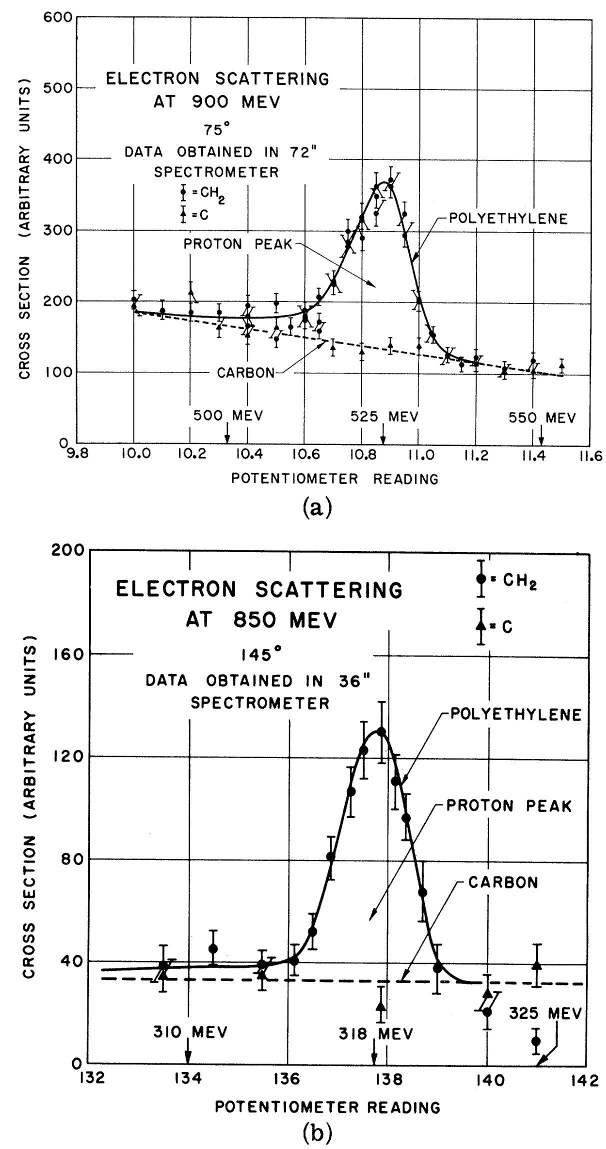


FIG. 2. (a) Electron-scattering peak obtained with a 0.237-in. polyethylene target at an incident energy of 900 Mev and a scattering angle of 75°. The target was at 45° with respect to the incident beam. (b) Same except parameters are 850 Mev, 145°, 36-in. spectrometer, and target at 0°.

peak obtained with the 72-in. spectrometer at an incident energy of 900 Mev and a scattering angle of 75°. The target material was polyethylene and we have subtracted the carbon background in analyzing the data to obtain the proton-scattering peak. The carbon data were obtained in the same run with a separate graphite target. In Fig. 2(b) we show a corresponding peak obtained in the 36-in. spectrometer at 850 Mev and 145°.

The cross sections obtained in this work are absolute cross sections and are based on the readings of the Faraday cup shown in Fig. 1 which gives the number of electrons in the main beam. The secondary emission monitor was an adjunct used as a monitor for the 72-in. spectrometer and was calibrated during each run with reference to the Faraday cup. The Faraday cup was the same unit used in previous experiments.[2] In our present experiments the vacuum pipe leading to the Faraday cup was not used.

It is difficult at the present time to estimate the errors associated with our absolute cross sections. The main uncertainty is the detection efficiency of our Čerenkov counters. These counters have been tested carefully but it is still possible that a 10% or smaller error remains in our efficiency measurements. Our efficiency measurements differ very little from 100% and we have therefore used this figure as the detector efficiency. Statistical errors are usually small compared with possible systematic errors and perhaps a measure of our errors should be the differences between individual measurements made under the same conditions of energy and angle. These differences are always less than ±10%. Another small source of uncertainty is the value of the dispersion constant of the 72-in. spectrometer. We have measured the dispersion constant to an accuracy of about 5%.

Our results are presented in Table I and include standard radiative corrections.[1] In addition to the cross sections in the Table we give the values of the square of the momentum transfer. In many cases we have given a single value as an average of several measured cross sections. As a general rule we believe our results are accurate to about ±10% because of the aforementioned possible errors. Relatively speaking, errors are probably less than ±5%. Our interpretation of the above results will be given in an accompanying paper.[3]

We understand that the Cornell group[4] is investigating the same electron-scattering problem.

Table I. Summary of results.

| $E$ (Mev) | $\theta$ (deg) | $q^2$ (fermi$^{-2}$) | $(d\sigma/d\Omega)\times10^{33}$ (cm$^2$/sr) |
|---|---|---|---|
| 597 | 60° | 6.96 | 67.9 |
| 597 | 90° | 11.20 | 8.76 |
| 597 | 120° | 14.06 | 2.65 |
| 650 | 135° | 16.97 | 1.51 |
| 700 | 60° | 9.16 | 38.0 |
| 700 | 75° | 12.01 | 11.2 |
| 700 | 135° | 18.90 | 0.955 |
| 700 | 145° | 19.43 | 0.778 |
| 750 | 45° | 6.86 | 136 |
| 750 | 75° | 13.45 | 10.0 |
| 750 | 90° | 16.06 | 4.08 |
| 750 | 135° | 20.86 | 0.728 |
| 750 | 141.5° | 21.24 | 0.735 |
| 750 | 145° | 21.42 | 0.580 |
| 775 | 135° | 21.86 | 0.644 |
| 800 | 45° | 7.70 | 104 |
| 800 | 60° | 11.53 | 23.5 |
| 800 | 75° | 14.93 | 8.19 |
| 800 | 90° | 17.75 | 2.99 |
| 800 | 120° | 21.64 | 0.888 |
| 800 | 135° | 22.86 | 0.605 |
| 800 | 145° | 23.44 | 0.360 |
| 850 | 45° | 8.59 | 80.6 |
| 850 | 60° | 12.77 | 17.8 |
| 850 | 75° | 16.46 | 5.62 |
| 850 | 120° | 23.60 | 0.711 |
| 850 | 135° | 24.88 | 0.509 |
| 850 | 145° | 25.50 | 0.371 |
| 875 | 40° | 7.56 | 127 |
| 875 | 45° | 9.05 | 82.0 |
| 875 | 60° | 13.42 | 15.7 |
| 875 | 145° | 26.54 | 0.376 |
| 900 | 45° | 9.51 | 61.5 |
| 900 | 60° | 14.06 | 14.3 |
| 900 | 75° | 18.03 | 5.35 |
| 900 | 90° | 21.24 | 2.09 |
| 900 | 145° | 27.58 | 0.347 |

Unfortunately we have no firm data of that group to compare with our results.

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[1]E. E. Chambers and R. Hofstadter, Phys. Rev. 103, 1454 (1956).

[2]R. Herman and R. Hofstadter, High-Energy Electron Scattering Tables (Stanford University Press, Stanford, California, 1960), and the work of F. Bumiller and R. Hofstadter shown in Fig. 8 of this reference.

[3]R. Hofstadter, F. Bumiller, and M. Croissiaux, following Letter [Phys. Rev. Letters 5, 263 (1960)].

[4]K. Berkelman and J. Cassels (private communication).

## SPLITTING OF THE PROTON FORM FACTORS AND DIFFRACTION IN THE PROTON*

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Electron-scattering studies of the proton obtained in the last few years have been summarized recently.[1] The measurements showed that the proton form factors ($F_1$, $F_2$) were less than unity, implying a finite structure, and lay in a region in which they were approximately equal to each other at momentum transfers ($q$) as high as $q^2 = 9.3$ in units of squared inverse fermis. At this value of the momentum transfer the measured ratio was $F_1/F_2 = 1.23 \pm 0.20$.[2] The experiments were confined to angles larger than 60° at the highest energies then obtainable (650 Mev) because of the limitation imposed by the energy-handling ability of the 36-in. spectrometer. It was therefore not possible to solve for $F_1$ and $F_2$ separately at values of $q^2 \geq 9.3$. Several independent experiments[2,3] indicated that the $F_1$ values were slightly greater than the $F_2$ values at the same momentum transfer, but for simplicity and ease of calculation, in the past, the ratio of form factors was usually taken to be unity.

We have now succeeded in splitting apart the two proton form factors. Because of the great interest in the proton form factors and because our data appear to be internally consistent, we wish to present in this paper some conclusions drawn from the experimental results given in the accompanying paper.[4]

Our procedure has been to solve for the separate form factors ($F_1$, $F_2$) at conditions lying between $7.7 \leq q^2 \leq 25$ by choosing a pair of experimentally measured cross sections at the same value of $q^2$ but at different correlated values of energy and angle. We have used the method of intersecting ellipses[5] to find the form factors.

Table I shows the values selected and the form factors found by combining the results. In a few cases, indicated by asterisks, we have used older data and combined the older values with the newly-measured cross section at the same value of $q^2$. In two cases (866 Mev, 75°; 675

Table I. Form factors $F_1$ and $F_2$.

| $q^2$ ($f^{-2}$) | $E_1$ (Mev) | $\theta_1$ (deg) | $(d\sigma/d\Omega)_1$ (cm²/sr) | $E_2$ (Mev) | $\theta_2$ (deg) | $(d\sigma/d\Omega)_2$ (cm²/sr) | $F_1$ | $F_2$ |
|---|---|---|---|---|---|---|---|---|
| 7.70 | 800 | 45° | $1.04 \times 10^{-31}$ | 400 | 124° | *$1.06 \times 10^{-32}$ | 0.520 | 0.490 |
| 9.16 | 700 | 60° | $3.80 \times 10^{-32}$ | 464 | 135° | *$6.26 \times 10^{-33}$ | 0.500 | 0.420 |
| 11.50 | 800 | 60° | $2.35 \times 10^{-32}$ | 500 | 135° | *$4.18 \times 10^{-33}$ | 0.451 | 0.341 |
| 14.06 | 900 | 60° | $1.43 \times 10^{-32}$ | 597 | 120° | $2.65 \times 10^{-33}$ | 0.423 | 0.214 |
| 16.97 | 866 | 75° | $5.56 \times 10^{-33}$ | 650 | 135° | $1.51 \times 10^{-33}$ | 0.430 | 0.160 |
| 18.03 | 900 | 75° | $5.35 \times 10^{-33}$ | 675 | 135° | $1.23 \times 10^{-33}$ | 0.451 | 0.108 |
| 21.24 | 900 | 90° | $2.09 \times 10^{-33}$ | 750 | 141.5° | $7.35 \times 10^{-34}$ | 0.405 | 0.087 |