Neutron Form Factors from Inelastic Electron-Deuteron Scattering*

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The differential cross section for quasielastic scattering of electrons from neutrons initially bound in deuterium has been measured at 90° and 120° laboratory angle for values of the four-momentum transfer squared equal to 11, 15, 20, 25, and 35 F^{-2}. The yield of momentum analyzed scattered electrons was measured using CD_2, CH_2, and C targets. The Durand theory for the effects of deuteron binding is used to extract experimental values for the ratio of the electron-neutron and electron-proton differential cross sections. Over most of the range of the experiment σ_n/σ_p is between 0.3 and 0.5. The neutron form factors obtained are consistent with previous measurements at lower momentum transfer. $|G_{En}|$ remains less than 0.3 and $|G_{Mn}|$ continues its decrease towards zero with increasing momentum transfer ($|G_{Mn}|<0.2$ at $q^2=35$ F^{-2}).

INTRODUCTION

THE extensive experimental data available on the elastic scattering of electrons by protons[1] has been fit rather well by the modified Rosenbluth formula,[2] relating the differential cross section to the two form factors characterizing the proton electric and magnetic structure. The functional dependence of the proton form factors on the four-momentum transfer in scattering has been qualitatively understood in terms of the exchange of vector-meson states.[3] Since the contributions to the form factors are identical in the case of isoscalar meson exchange and of opposite sign for isovector-meson exchange, it becomes desirable to supplement the rather complete proton form-factor data now available with comparable data on the neutron form factors.

Instead of scattering electrons from free neutrons, experimenters have been obliged to use indirect techniques: (1) The scattering of neutrons by atomic electrons,[4] which measures the initial slope of the charge form factor at zero momentum transfer; (2) the elastic scattering of electrons by deuterons,[5] which is limited by counting rate and deuteron wave function uncertainties to momentum transfers well below $q^2=10$ F^{-2} [6]; and (3) the quasielastic scattering of electrons by neutrons loosely bound in deuterium. The interpretation of the latter class of experiments is based on the impulse approximation,[7] which treats the proton and neutron as free particles moving with a known initial momentum distribution. The calculated corrections to the impulse approximation[8] are quite appreciable at low momentum transfers, and recent experiments[9] indicate that the theory is not completely understood. Above $q^2=10$ F^{-2}, however, the corrections are estimated to be less than 1%, and uncertainties in the theory should not seriously affect the accuracy of the derived neutron form factors. In the following we report such an experimental measurement of the neutron form factors in the range of momentum transfer from $q^2=11$ F^{-2} to as high a value as was experimentally feasible at the Cornell synchrotron.

APPARATUS

At the peak of the acceleration cycle the circulating electron beam of the Cornell synchrotron was intercepted by a deuterated polyethelene (CD_2) target[10] rotating in synchronism with the magnet excitation. The effective product of electron flux and total traversal thickness per electron was determined by the yield of forward bremsstrahlung monitored with a standard quantameter.[11] The details of the beam energy and flux calibrations have been described elsewhere.[12]

* Supported in part by the U. S. Office of Naval Research.

[1] F. Bumiller, M. Croissiaux, E. Dally, and R. Hofstadter, Phys. Rev. **124**, 1623 (1961); P. Lehmann, R. Taylor, and R. Wilson, *ibid.* **126**, 1183 (1962); D. Yount and J. Pine, *ibid.* **128**, 1842 (1962); B. Dudelzak, G. Sauvage, and P. Lehmann, Nuovo Cimento **28**, 18 (1962); D. J. Drickey and L. N. Hand, Phys. Rev. Letters **9**, 521 (1962); K. Berkelman, M. Feldman, R. M. Littauer, G. Rouse, and R. R. Wilson, Phys. Rev. **130**, 2061 (1963); J. R. Dunning, Jr., K. W. Chen, N. F. Ramsey, J. R. Rees, W. Schlaer, J. K. Walker, and R. Wilson, Phys. Rev. Letters **10**, 500 (1963); K. Berkelman, M. Feldman, and G. Rouse, Phys. Letters **6**, 116 (1963); K. W. Chen, A. A. Cone, J. R. Dunning, Jr., S. G. F. Frank, N. F. Ramsey, J. K. Walker, and R. Wilson, Phys. Rev. Letters **11**, 561 (1963).

[2] M. N. Rosenbluth, Phys. Rev. **79**, 615 (1950); K. Barnes, Phys. Letters **1**, 166 (1962); L. N. Hand, D. G. Miller, and R. Wilson, Phys. Rev. Letters **8**, 110 (1962).

[3] W. R. Frazer and J. Fulco, Phys. Rev. Letters **2**, 365 (1959); S. Bergia, S. Fubini, A. Stanghellini, and C. Villi, *ibid.* **6**, 367 (1961).

[4] L. Foldy, Rev. Mod. Phys. **30**, 471 (1958).

[5] J. I. Friedman, H. W. Kendall, and P. A. M. Gram, III, Phys. Rev. **120**, 992 (1960); B. Grossetête and P. Lehmann, Nuovo Cimento **28**, 240 (1962); D. J. Drickey and L. N. Hand, Phys. Rev. Letters **9**, 521 (1962). At very low momentum transfers recent elastic electron-deuteron data tend to contradict the well-established neutron-electron result, indicating a possible failure in the theoretical interpretation of the electron-deuteron cross section in terms of nucleon form factors. This may eventually be clarified by electron-He^3 and electron-H^3 scattering data such as those of L. I. Schiff, H. Collard, R. Hofstadter, A. Johansson, and M. R. Yearian, Phys. Rev. Letters **11**, 387 (1963).

[6] The four-momentum transfer squared is taken to be positive for space-like momentum transfer. One $F^{-2}=197$ MeV/c.

[7] A. Goldberg, Phys. Rev. **112**, 618 (1958).

[8] L. Durand, III, Phys. Rev. **123**, 1393 (1961).

[9] T. A. Griffy, R. Hofstadter, E. B. Hughes, T. Janssens, and M. R. Yearian (to be published).

[10] In the initial trials a liquid deuterium target was used, but was abandoned because the bremsstrahlung yield was mainly sensitive to the 0.0005-in. aluminum wall of the target, and the total traversal thickness in the aluminum relative to that in deuterium could not be controlled with sufficient accuracy.

[11] R. R. Wilson, Nucl. Instr. **1**, 101 (1957).

[12] K. Berkelman, M. Feldman, R. M. Littauer, G. Rouse, and R. R. Wilson, Phys. Rev. **130**, 2601 (1963).

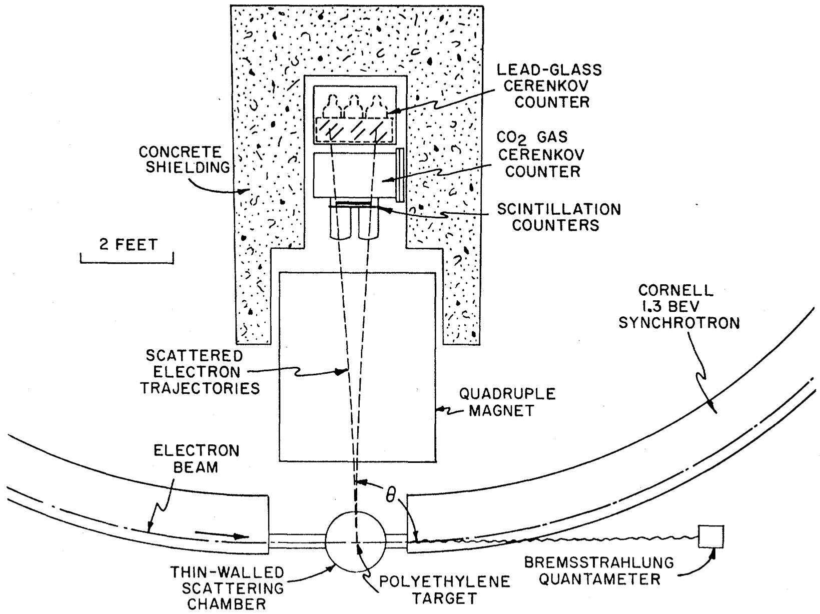

FIG. 1. A plan view of the experimental apparatus, shown for the ease of 90° scattering angle.

Scattered electrons emerged from the synchrotron vacuum chamber (see Fig. 1) through a thin window and were analyzed in momentum by a quadrupole magnet set for focusing in the vertical plane (see Fig. 2). For electrons of a given momentum the image of the target (essentially a point source) was a horizontal line perpendicular to the quadrupole axis at a distance behind the magnet determined by the momentum and the current in the magnet coils. The momentum resolution was set by the size of the scintillation counter placed at the target image and by the vertical aperture of the quadrupole. The resolution function, shown in Fig. 3, was made wide enough to span a sizeable fraction of the spectrum of electrons quasielastically scattered by the proton and neutron in deuterium. The calculated momentum-resolution function was verified experimentally by observing electrons elastically scattered by free protons as a function of excitation current in the quadrupole.

A major difficulty in measuring the electron-scattering yield from deuterium is the pion background. In an electron-proton scattering experiment the π^- background is negligible, first because negative pions can be produced only in association with positive pions, and secondly because it is impossible at any given angle to produce a pion with the same momentum as an elastically scattered electron. Negative pions, however, can be produced singly (and hence more copiously) from neutrons, and the initial momentum of the neutrons is enough to allow some pions to emerge at the momentum of a quasielastically scattered electron. The distribution of pions falls off more gradually with energy and angle than the rapid $E^{-2}\theta^{-4}$ dependence characteristic of the scattered electrons, so that at large energies and angles the negative pions from deuterium greatly outnumber the electrons even in the quasielastic momentum channel.

In order to decrease the pion contamination in the

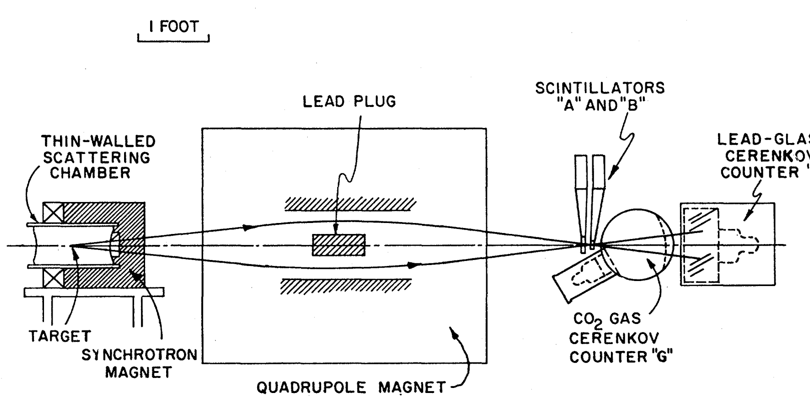

FIG. 2. A side view of the experimental apparatus.

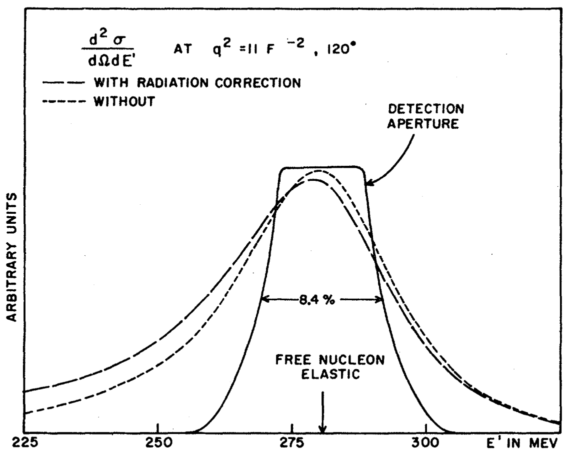

FIG. 3. A typical plot of the energy spectrum of electrons inelastically scattered from deuterium. Also shown is the electron detection efficiency as a function of energy. The convolution of the two curves is proportional to the observed counting rate.

measured electron rates simultaneous pulses in four counters were required: the momentum-defining scintillator, a second scintillator, a gas Cerenkov counter, and a lead-glass Cerenkov counter (see Figs. 1 and 2). A large light pulse in the lead-glass counter signified an electromagnetic shower initiated by a high-energy electron. The gas counter (500 lb/in.^{2} of CO_2) had a refractive index of 1.014, or a velocity threshold for Cerenkov radiation of $0.986c$, sufficiently high to exclude all pions of momentum less than 800 MeV/c. The coincidence resolving time was about 8 nsec. Accidental coincidences, chiefly due to the high noise rate in the gas counter, were monitored by a similar coincidence circuit with one input channel delayed. The accidental rate was about 10% or less and was subtracted from the data. The pulse-height distribution in each of the four counters was continuously monitored.

PROCEDURE

A determination of the electron-neutron cross section based on the total quasielastic electron yield from deuterium[13] requires first a subtraction of the proton contribution, which must be determined from a separate measurement employing a CH_2 target instead of CD_2. Although proton data are available in the literature, it is important to measure the electron-deuteron and electron-proton reactions under identical experimental conditions to minimize the effects of systematic errors in the subtraction. For each determination of the neutron cross section the momentum acceptance band of the electron spectrometer was centered at the momentum corresponding to the elastic scattering from a free nucleon (see Fig. 3) and the electron coincidence rate was measured successively with CD_2, CH_2, and C targets, cycled frequently to minimize systematic errors. This was done at laboratory scattering angles of 90° and 120° for each of five values of the momentum transfer, $q^2 = 11$, 15, 20, 25, and 35 F^{-2}, covering a range of incident energies from 509 to 1265 MeV.

Each measurement totaled about 15 000 counts distributed among the three targets. The circulating beam intensity was about 10^{10} electrons per pulse, 30 pulses per second, each pulse lasting about 0.5 msec. The effective thickness of the target taking into account multiple beam traversals was approximately 0.01 radiation lengths as determined by the bremsstrahlung monitor. The solid angle subtended by the electron spectrometer was 5.4 msr for the 90° measurements and 13.6 msr for the 120° measurements. The counting rate varied from 30 counts per minute to one count per minute. The rates with deuterated and normal polyethylene were approximately equal (a consequence of the choice of spectrometer momentum resolution) while the carbon rates were about half of the polyethylene rates. An approximate check on the detection sensitivity for pions was obtained by reversing the spectrometer polarity, assuming the π^+/π^- ratio from deuterium to be approximately one and the e^+/e^- ratio negligibly small. The pion contamination was found to be negligible at all but the highest value of momentum transfer,[14] where a correction of about 10% based on the reversed polarity rate was applied to the deuterium data.

To improve the pion rejection the pulse-height discrimination levels in the gas counter and the shower counter were purposely set rather high, and the counting efficiency for scattered electrons was somewhat less than 100%. For this reason, only the ratios of the deuterium and hydrogen rates were used in the analysis. This also eliminated any systematic error arising from the fact that different quadrupole magnets were used at the two scattering angles: at 90° a conventional hyperbolic quadrupole for maximum focusing power, and at 120° a rectangular current-sheet quadrupole[15] for greater aperture. Although the absolute rates with the CH_2 target were not used in the analysis, with reasonable estimates of the counting efficiency and the spectrometer apertures they gave experimental electron-proton cross sections in satisfactory agreement with published results.

ANALYSIS

The impulse approximation[7] implies a simple relation between the sum of the free proton and neutron cross

[13] A neutron-electron coincidence measurement as first proposed by L. Durand, III, Phys. Rev. **115**, 1020 (1959) and later carried out at low momentum transfers by P. Stein, R. W. McAllister, B. D. McDaniel, and W. M. Woodward, Phys. Rev. Letters **9**, 403 (1962) would have provided the most direct determination of the electron-neutron cross section. However, at high-momentum transfers, it is found that the background rate in the neutron detector becomes intolerable and coincidence measurements are a practical impossibility.

[14] Presumably the pion contamination is due to knock-on electrons and showers from the decay of neutral pions created by charge-exchange pion scattering.

[15] L. N. Hand and W. K. H. Panofsky, Rev. Sci. Instr. **30**, 927 (1959).

sections and the deuteron-electrodisintegration yield, either at the peak of the scattered electron spectrum,

$$\frac{d^2\sigma_d}{d\Omega dE'}=\frac{8.8E}{|\mathbf{q}|E'}\left(\frac{d\sigma_p}{d\Omega}+\frac{d\sigma_n}{d\Omega}\right),$$

or integrated over the full spectrum,

$$\int\frac{d^2\sigma_d}{d\Omega dE'}dE'=\frac{d\sigma_p}{d\Omega}+\frac{d\sigma_n}{d\Omega}.$$

The present measurement however represents an integral over a portion of the spectrum in the vicinity of the quasielastic peak (see Fig. 3), and therefore a detailed knowledge of the theoretical shape of the electron spectrum is necessary in order to extract an experimental value for the sum of the free-nucleon cross sections. But in order to calculate the spectrum shape one must make some assumption about the variation of the free-nucleon cross sections with momentum transfer. Electron-proton cross sections were obtained from recent fits to the proton form-factor data,[1] and an educated guess was made for the electron-neutron cross sections. Using these values and assuming a repulsive core s-state wave function for the deuteron,[16] Durand's expression for $d^2\sigma_d/d\Omega dE'$ as a function of E was[17] evaluated numerically for each of the ten values of θ and q^2, then modified by the radiation correction (see Fig. 3) according to the prescription of Meister and Griffy,[18] and corrected for final-state interactions and d-state contribution.[19] The calculated spectrum function $d^2\sigma_d/d\Omega dE'$ was integrated over the momentum resolution function $R(E)$ (normalized to one at its maximum value). A similar integration was performed over the spectrum $d^2\sigma_p/d\Omega dE'$ for radiative scattering from free protons. The predicted deuterium-to-hydrogen counting rate ratio based on the assumed free-nucleon cross sections is then

$$\frac{D}{H}=\left(\int\frac{d^2\sigma_d}{d\Omega dE'}R(E')dE'\right)\left(\int\frac{d^2\sigma_p}{d\Omega dE'}R(E')dE'\right)^{-1}.$$

The predictions were compared to the actual measured ratios, the neutron cross sections were scaled up or down from the initial assumption, and the whole calculation was repeated until neutron cross sections were found which gave agreement with the observed counting rates.

An important source of instrumental error was the determination of the momentum resolution function. An uncertainty of about 2% in momentum acceptance width, due to measurement error in the counter and magnet dimensions and small effects such as multiple scattering in the spectrometer air path, propagated as a 5% error in σ_n/σ_p. Errors arising from uncertainties in the detection solid angle, the beam-monitor calibration, and the energy calibration were eliminated by basing the analysis on ratios of counting rates.

Finally, the results are valid only to the extent that the theory of the deuteron used in the analysis is reliable. Reasonable choices of deuteron wave function (e.g., Hulthén, repulsive core) give theoretical values of $d^2\sigma_d/d\Omega dE'$ varying by less than 2% in the vicinity of the quasielastic peak. The radiation corrections are probably good to about 2% of the total yield[18] and probably contribute a much smaller uncertainty in the ratio. The combined d-state and final-state interaction effect is probably known to about 2% of the total.[8,19] Taking the net theoretical uncertainty in the deuteron electrodisintegration yield as 4%, one arrives at an uncertainty of about 12% in the experimental σ_n/σ_p.

TABLE I. Experimental deuterium-to-hydrogen counting rate ratios (corrected for accidental coincidences, pion contamination and carbon background) and derived ratios of electron-neutron and electron-proton differential cross sections for elastic scattering. The indicated experimental errors include only counting statistics (see text).

	q^2, in F^{-2}	D/H	σ_n/σ_p
90°	11	0.79±0.03	0.42±0.07
	15	0.84±0.03	0.44±0.07
	20	0.82±0.05	0.39±0.11
	25	0.86±0.05	0.42±0.10
	35	0.92±0.13	0.50±0.23
120°	11	0.75±0.03	0.46±0.08
	15	0.80±0.04	0.49±0.09
	20	0.78±0.04	0.41±0.09
	25	0.75±0.04	0.33±0.09
	35	0.70±0.06	0.21±0.14

RESULTS

In Table I are listed the experimental deuterium-to-hydrogen counting rate ratios. Also tabulated are the derived neutron-proton cross-section ratios. The indicated experimental errors include only counting statistics and should closely represent the relative accuracy from point to point. Other errors, due to the uncertainty in momentum resolution and theoretical uncertainties in the data reduction, are very strongly correlated from point to point and mainly affect the over-all scale of the results. For this reason they will not be included in the statistical treatment of the data.

[16] Equation (35.1) of Ref. 8. The numerical values of the parameters are those given on p. 1404 of Ref. 8.

[17] Equations (10), (11), (15.1), (29), and (83) of Ref. 8. The neutron-proton interference terms are extremely small and are neglected.

[18] N. T. Meister and T. A. Griffy, Phys. Rev. **133**, B1032 (1964). We treat the energy spectra of electrons scattered from deuterium and from hydrogen in the same way. The difference between the electron-proton radiation correction calculated in this way and the correction given by N. T. Meister and D. R. Yennie, Phys. Rev. **130**, 1210 (1963) is small but the effect on the computed σ_n/σ_p is not quite negligible. Terms arising from radiation by the proton, corresponding to those occurring in the Meister and Yennie formula, were added to the Meister and Griffy formula.

[19] J. Nuttall and M. L. Whippman, Phys. Rev. **130**, 2495 (1963). The combined d-state and final-state interaction correction is less than 1%.

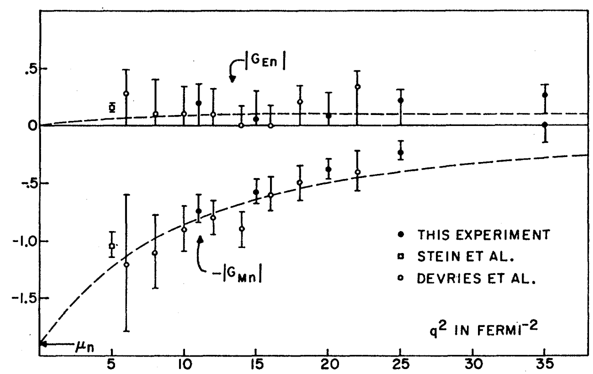

FIG. 4. A comparison of the neutron form factors determined in this experiment with earlier published data from Refs. 13 and 20. The curves show the four-pole Clementel-Villi fit described in the text.

The measured σ_n/σ_p ratios and the available proton data[1] determine the electron-neutron scattering cross sections. Then assuming the Rosenbluth formula[2] one derives $|G_{En}|$ and $|G_{Mn}|$ from the two cross sections at each momentum transfer. The results are given in Table II and plotted in Fig. 4. Also shown in the graph are other data at lower momentum transfers obtained from deuteron electrodisintegration.[13,20] The agreement is good. Notice however, that the electric form factor cannot be regarded as having been adequately measured in this experiment. Such a measurement requires a determination of the cross section at small scattering angles and higher incident energies than were available in this experiment. It is clear however that values of $|G_{En}|$ higher than 0.3 are very unlikely.

At least one conclusion can probably be drawn from these data without a specific model of the form factors. The fact that G_{En} remains small and $|G_{Mn}|$ rapidly decreases with increasing q^2 strongly suggests that both form factors are asymptotically approaching zero. Such a behavior has already been noted in the proton form factors[21] and has been predicted for neutron form factors by Sachs.[22]

FORM-FACTOR MODELS

There is an infinite variety of functional forms which can fit the momentum transfer dependence of the form factors by proper choice of the parameters. Instead of merely finding the best interpolation formula we use the maximum outside information on form-factor behavior to find the simplest representation consistent with all the data and well-founded theoretical expectations. We therefore consider the following restrictions on the functional form.

TABLE II. The absolute values of the neutron form factors determined in this experiment.

q^2, in F^{-2}	$\lvert G_{En}\rvert$	$\lvert G_{Mn}\rvert$
11	$0.19^{+0.17}_{-0.19}$	$0.74^{+0.11}_{-0.13}$
15	$0.04^{+0.25}_{-0.04}$	$0.59^{+0.09}_{-0.12}$
20	$0.08^{+0.20}_{-0.08}$	$0.39^{+0.08}_{-0.10}$
25	$0.21^{+0.10}_{-0.21}$	$0.24^{+0.07}_{-0.10}$
35	$0.26^{+0.08}_{-0.16}$	$0.0^{+0.16}_{-0.0}$

(1) Electron-nucleon scattering takes place through the exchange of vector-meson states. Each vector-meson state of mass m contributes a pole term $c_m(1+q^2/m^2)^{-1}$ to the isoscalar form factor[23] if the meson has isospin zero or to the isovector form factor if the meson has isospin one. We then expect a Clementel-Villi formula[24] for each form factor:

$$G=\Sigma[c_i(1+q^2/m_i^2)^{-1}]+c_0,$$

where c_0 represents the interaction of the photon directly with the bare nucleon core.

(2) The known vector mesons are the ρ, the ω, and the ϕ. Because of its width the effective ρ mass may be as low as 650 MeV.[25]

(3) There are no core terms in either the proton or neutron form factors.

(4) At the time-like momentum transfer $q^2=-4M$, far removed from the range available to electron scattering experiments, we have $G_E=G_M$ both for the proton and the neutron, or equivalently, for the isoscalar and isovector form factors.[26]

A simple three-pole ρ, ω, ϕ, Clementel-Villi fit to the form factors cannot be made, since G_{Mv} and G_{Ev} cannot be made equal at one value of q^2 without being equal at all q^2, including $q^2=0$ where they are clearly unequal. Even without such a condition the three-pole fit is extremely poor. The addition of core terms makes it possible to fit the proton data,[27] but the data of the

[20] C. DeVries, R. Hofstadter, and R. Herman, Phys. Rev. Letters **8**, 381 (1962). The data shown in Fig. 4 are taken from the analysis by L. N. Hand, D. G. Miller, and R. Wilson, Rev. Mod. Phys. **35**, 335 (1963) since DeVries *et al.* do not give actual experimental form factors (neither is it possible to make a direct comparison of measured cross sections). More recent measurements of the Stanford group (Ref. 9) at $q^2\leq 10$ F^{-2} give neutron form factors which tie on well with the data of this experiment.

[21] K. W. Chen, A. A. Cone, J. R. Dunning, Jr., S. G. F. Frank, N. F. Ramsey, J. K. Walker, and R. Wilson, Phys. Rev. Letters **11**, 561 (1963).

[22] R. G. Sachs, Phys. Rev. **126**, 2256 (1962).

[23] We define the isoscalar and isovector electric form factors as follows: $G_{Es}=\frac{1}{2}(G_{Ep}+G_{En})$ and $G_{Ev}=\frac{1}{2}(G_{Ep}-G_{En})$. The isoscalar and isovector magnetic form factors are defined similarly.

[24] E. Clementel and C. Villi, Nuovo Cimento **4**, 1207 (1956).

[25] J. S. Ball and D. Y. Wong, Phys. Rev. **130**, 2112 (1963).

[26] This follows from the relation between the helicity form factors and the Dirac and Pauli form factors plus the assumption the F_2 has no pole at $q^2=-4M^2$. This observation is due to S. Bergia and L. S. Brown, Proceedings of the International Conference on Nucleon Structure, Stanford, 1963 (to be published).

[27] M. W. Kirson, Phys. Rev. **132**, 1249 (1963).

present experiment cannot simultaneously be fitted. If one also allows the effective mass of the ρ to vary, it is possible to fit all the data[28] but at the sacrifice of assuming a ρ mass well below 600 MeV. We take this as strong evidence for additional exchange contributions other than the assumed ρ, ω, and ϕ poles. There is some evidence[29] that the $\pi\omega$ resonance observed at 1220 MeV has spin one and negative parity, in which case it could be expected to contribute a second pole term to the isovector form factors. Using a four-pole Clementel-Villi representation (ρ, ω, ϕ, and ρ') for the form factors we compute the electron-proton and electron-neutron cross sections. The pole residues are fitted by least squares to the most recent published proton cross sections[1] and neutron-proton ratios[30] (mainly the data of the present experiment), using the initial values of the form factors, the initial slope of G_{En}[4], and the equality of electric and magnetic form factors at $q^2=-4M^2$ as constraints (leaving only one parameter to be determined). The following best fit is obtained:

$$G_{Es}=\frac{1.39\pm0.10}{1+q^2/15.7}-\frac{0.89\pm0.10}{1+q^2/26.7},$$

$$G_{Ev}=\frac{1.25\pm0.10}{1+q^2/13}-\frac{0.75\pm0.10}{1+q^2/37},$$

$$G_{Ms}=0.880\left(\frac{1.44\pm0.05}{1+q^2/15.7}-\frac{0.94\pm0.05}{1+q^2/26.7}\right),$$

$$G_{Mv}=4.706\left(\frac{0.78\pm0.03}{1+q^2/13}-\frac{0.28\pm0.03}{1+q^2/37}\right).$$

The χ^2 value is 688 for 131 degrees of freedom. Even making reasonable allowances for the unaccounted-for systematic differences among experiments, this does not appear to be a particularly good fit (see also Fig. 4). The χ^2 is negligibly affected by removing the restriction that $G_{Ep}=G_{Mp}$ and $G_{En}=G_{Mn}$ at $q^2=-4M^2$.[31] It may be that the assumed ρ' mass is incorrect or that there are still more exchange contributions which should be included. The data are insufficient to distinguish the various possibilities.

As Alles and Bergia[32] have shown, a knowledge of the residues of the pole terms gives important information on coupling constants in the unitary symmetry scheme. It is clear, however, that one cannot hope for any precision until the number and location of pole contributions are known.

ACKNOWLEDGMENTS

We are indebted to Professor R. R. Wilson and Professor M. Feldman for their valuable assistance during the early phases of the experiment.

[28] C. DeVries, R. Hofstadter, A. Johansson, and R. Herman, Phys. Rev. **134**, B848 (1964).

[29] D. D. Carmony, R. L. Lander, C. Rindfleisch, N. Xuong, and P. Yager, Phys. Rev. Letters **12**, 254 (1964).

[30] Besides the data of the present experiment we include the data of Stein *et al.* (Ref. 13). The data of DeVries *et al.* (Refs. 20 and 28) could not be used in the fitting, because experimental values for σ_n/σ_p were not reported by these authors. The data from elastic electron-deuteron scattering (Ref. 5) are not included, because they conflict with the neutron-electron result (Ref. 4).

[31] If we replace the condition that electric and magnetic form factors be equal at $q^2=-4M^2$ by the condition that $G_{Ms}=(\mu_p+\mu_n)G_{Es}$ and $G_{Mv}=(\mu_p-\mu_n)G_{Ev}$, suggested by A. P. Balachandran, P. G. O. Freund, and C. R. Schumacher, Phys. Rev. Letters **12**, 209 (1964), the fit becomes appreciably worse. The four-pole fit suggested by these authors is very much worse ($\chi^2/N>10^5$).

[32] W. Alles and S. Bergia, Nuovo Cimento **31**, 262 (1964).