High-Energy Single-Arm Inelastic *e-p* and *e-d* Scattering at 6 and 10°

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Differential cross sections for electron scattering from hydrogen and deuterium in the deep-inelastic region show that the neutron cross section is significantly smaller than the proton cross section over a large part of the kinematic region studied. Although νW_2^d differs in magnitude from νW_2^p, it exhibits a similar scaling behavior.

Previous studies[1,2] of proton structure by deep-inelastic electron scattering have been extended to the neutron[3] in an experiment measuring cross sections for electron scattering from hydrogen and deuterium. We have measured the cross section for electrons of incident energy E scattering through an angle θ to a final energy E', for θ of 6 and 10° and for various E between 4.5 and 19.5 GeV. The data were taken at fixed values of θ and E, varying E' in discrete steps between energies corresponding to elastic e-p scattering and 2.5 GeV. These data spanned a range in four-momentum transfer squared $Q^2 = 4EE'\sin^2(\theta/2)$ of $0.1 < Q^2 < 8.7$ GeV^2; in the electron energy loss $\nu = E - E'$ of $0.1 < \nu < 17.0$ GeV; and in the mass of the unobserved final hadronic state, $W = (M^2 + 2M\nu - Q^2)^{1/2}$, of $M \leq W < 5.7$ GeV, where M is the proton mass. The results presented here are obtained from the subset of the data within the kinematic limits $W > 2.0$ GeV, $Q^2 > 1.0$ GeV^2, and $E' > 3.0$ GeV, except as noted.[4]

The primary electron beam from the Stanford Linear Accelerator Center was energy analyzed to a width $\Delta E/E = \pm 0.25\%$ ($\pm 0.1\%$ for most points at $W < 2.2$ GeV) and traversed target cells containing 7 cm of hydrogen or deuterium.[5] Two independent toroidal charge monitors,[6] which were calibrated against a Faraday cup at every E, measured the amount of charge incident on the target.

Scattered particles were analyzed with a double-focusing magnetic spectrometer capable of momentum analysis to 20 GeV/c. Slits limited the vertical angular acceptance to ± 4.2 mrad. Two scintillation-counter hodoscopes were used to limit the horizontal (scattering plane) angular acceptance to ± 3.7 mrad, and the momentum acceptance to $^{+1.55}_{-1.70}\%$.

Electrons were distinguished from other particles, primarily pions, by using information from a threshold Cherenkov counter and a telescope of counters constituting a lead-Lucite cascade-shower detector.

The measured electron yields were converted to differential cross sections $d^2\sigma(E, E', \theta)/d\Omega dE'$ after corrections were made for fast-electronics dead time, computer-sampling dead time, electron detection and identification inefficiencies, and target density variations. These corrections had estimated errors ($\lesssim 1\%$ total) which were added in quadrature to the counting errors. Yields from an empty replica target cell were measured and subtracted from the full-target yields. Electron yields from π^0 decay and pair-production processes, obtained by reversing the spectrometer polarity and measuring positron yields, were also subtracted.

There are systematic experimental uncertainties which affect the absolute measured cross sections but cancel in the ratios of deuterium to hydrogen cross sections. These arise from spectrometer solid angle and momentum acceptance (± 2%); scattering angle (± 0.1 mrad, or ± 1% in the cross sections); energy calibration of the incident and scattered electron beams (± 0.2%, or ± 1% in the cross sections); calibration of the charge monitors (± 0.5%); and counter efficiencies (± 1%). Systematic errors which do not cancel in the ratios are target lengths (± 0.6%), and target densities and purities (± 0.8%).

Radiative corrections to the measured cross sections were computed using two different procedures.[2,4,7] In both procedures the radiative tails from elastic (e-p and e-d) or quasielastic (e-d) scattering were subtracted before the remaining inelastic cross sections were corrected. We have taken the mean of the two sets of results to determine our final cross sections. The results from the two procedures differed typically from their mean by 1.5% and never by more than 3%. The hydrogen-to-deuterium ratios found from the two procedures differed by typically $\lesssim 0.5\%$. Taking into account these differences, we estimate the systematic uncertainties due to these corrections to be ± 5% in the absolute cross sections for $E' = 3.0$ GeV, decreasing to ± 3% for $E' > 4.0$ GeV. We estimate the systematic uncertainties in the ratios to be half those in the cross sections.

Where they overlap, the hydrogen cross sections are consistent with our previous results at the Stanford Linear Accelerator Center,[1] and results obtained at Deutsches Elektronen Synchrotron and Cornell University.[8]

Separate determinations of the structure functions $W_1(\nu, Q^2)$ and $W_2(\nu, Q^2)$[9] for the proton and deuteron directly from the cross sections require data over a range of angles. This experiment alone covers too small an angular range to permit an accurate determination. Alternatively, W_2 can be expressed in terms of the cross sections, kinematic variables, and $R = \sigma_s/\sigma_t$, the ratio of total absorption cross sections for longitudinal and transverse virtual photons. The most recent determination of R uses data from this experiment and a similar experiment at larger angles,[10,11] with results that are consistent with $R_p = R_d = 0.18 \pm 0.10$, and $R_n = 0.18 \pm 0.16$.[11] We use $R = 0.18$ to compute for the proton and deuteron

$$\nu W_2 = \frac{\nu\, d^2\sigma/d\Omega dE'}{(d\sigma/d\Omega)_{\rm Mott}}\left[1 + \frac{2}{1+R}\left(1 + \frac{\nu^2}{Q^2}\right)\tan^2(\theta/2)\right]^{-1}.$$

Changing R by ± 0.10 changes νW_2 by at most 7% and usually by much less.

Previous experiments[1,2] showed that $\nu W_2^{\,p}$ was consistent with the scaling suggestion of Bjorken,[12] i.e., that $\nu W_2^{\,p}$ was a function only of $\omega = 2M\nu/Q^2$ in the limit ν and $Q^2 \to \infty$. It was also shown that scaling occurred over a larger kinematic range for $\nu W_2^{\,p}$ expressed as a function of $\omega' = 1 + W^2/Q^2$ instead of ω. Our results, in Fig. 1, illustrate that $\nu W_2^{\,d}$, as well as $\nu W_2^{\,p}$, exhibits this scaling behavior. We have concluded that, within the statistical and estimated systematic errors, $\nu W_2^{\,d}$ and $\nu W_2^{\,p}$ are consistent with scaling in ω' at least for $W > 2$ GeV and $Q^2 > 1$ GeV^2. The scaling behavior in ω is also similar to that observed previously.[1]

The structure functions and cross sections for the free neutron were determined from those of the proton and deuteron, using an impulse approximation to correct for the effects of the Fermi motion of the nucleons in the deuteron.[10,13] We emphasize that for the data presented in this paper, these corrections are small (< 3%, averag-

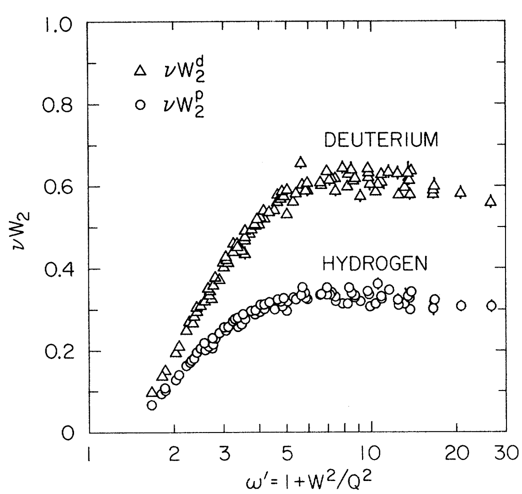

FIG. 1. $\nu W_2^{\,p}$ and $\nu W_2^{\,d}$ versus ω'. Data are from the region $Q^2 > 1.0$ GeV^2, $W > 2.0$ GeV. $R_p = R_d = 0.18$. Errors shown are statistical only. In most cases the error bars are smaller than the symbols.

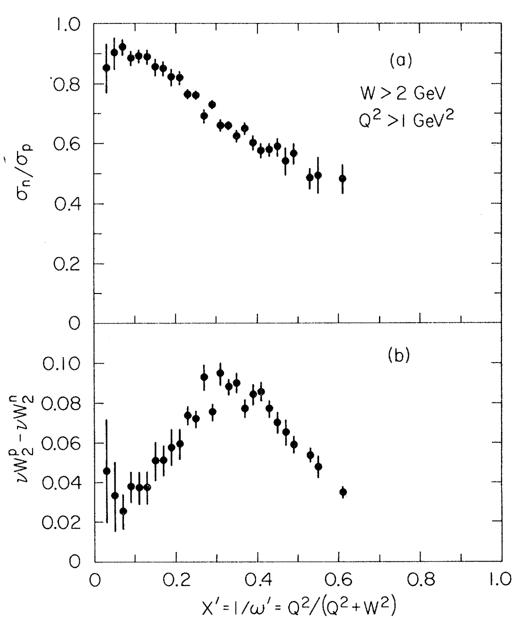

FIG. 2. (a) σ_n/σ_p versus x'. For $R_p = R_d = R_n$ these points are also $W_2^{\,n}/W_2^{\,p}$ and $W_1^{\,n}/W_1^{\,p}$. (b) $\nu(W_2^{\,p} - W_2^{\,n})$ versus x', assuming $R_p = R_d = R_n = 0.18$. The errors shown are statistical only.

TABLE I. Ratios σ_n/σ_p and differences $\nu(W_2^p - W_2^n)$ versus x'. These are plotted in Figs. 2(a) and 2(b). The errors are statistical only.

x'	σ_n/σ_p	$\nu(W_2^p - W_2^n)$
0.030	0.853 ± 0.085	0.0456 ± 0.0263
0.050	0.898 ± 0.054	0.0328 ± 0.0176
0.070	0.920 ± 0.028	0.0252 ± 0.0089
0.090	0.884 ± 0.025	0.0378 ± 0.0082
0.110	0.890 ± 0.024	0.0369 ± 0.0082
0.130	0.887 ± 0.025	0.0372 ± 0.0084
0.150	0.853 ± 0.029	0.0510 ± 0.0099
0.170	0.848 ± 0.023	0.0510 ± 0.0078
0.190	0.819 ± 0.028	0.0576 ± 0.0091
0.210	0.818 ± 0.023	0.0594 ± 0.0075
0.230	0.763 ± 0.016	0.0739 ± 0.0049
0.250	0.760 ± 0.014	0.0722 ± 0.0043
0.270	0.690 ± 0.021	0.0927 ± 0.0064
0.290	0.731 ± 0.015	0.0754 ± 0.0042
0.310	0.660 ± 0.021	0.0945 ± 0.0057
0.330	0.661 ± 0.016	0.0880 ± 0.0042
0.350	0.625 ± 0.021	0.0900 ± 0.0050
0.370	0.649 ± 0.021	0.0772 ± 0.0046
0.390	0.602 ± 0.025	0.0844 ± 0.0053
0.410	0.574 ± 0.024	0.0858 ± 0.0048
0.430	0.577 ± 0.022	0.0770 ± 0.0041
0.450	0.586 ± 0.032	0.0700 ± 0.0054
0.470	0.539 ± 0.046	0.0654 ± 0.0065
0.490	0.564 ± 0.034	0.0594 ± 0.0047
0.530	0.482 ± 0.035	0.0540 ± 0.0036
0.550	0.492 ± 0.060	0.0481 ± 0.0057
0.610	0.480 ± 0.048	0.0350 ± 0.0032

ing 1%) and that uncertainties in the corrections have correspondingly small effects. In addition, the neutron cross sections are quite insensitive to the uncertainties in the values of R_p and R_n used in their determination.

Figure 2(a) shows the ratios σ_n/σ_p of free neutron-to-proton differential cross sections versus $x' = 1/\omega'$. The plotted points are averages of all the data in each interval of 0.02 in x'. These are identical to the ratios $\nu W_2^n/\nu W_2^p$ or W_1^n/W_1^p for $R_n = R_p$.

Figure 2(b) shows the differences $\nu(W_2^p - W_2^n)$, again averaged over intervals of 0.02 in x'. The values plotted in Figs. 2(a) and 2(b) are derived from the data shown in Fig. 1 and are given in Table I. The prominent peak is in the kinematic region where R is best known experimentally and where the uncertainties due to radiative corrections are relatively small. The behavior of $\nu(W_2^p - W_2^n)$ at small x' cannot be resolved with these data.

Table II gives results for integrals over νW_2 interpolated to fixed Q^2 for the proton and deuteron:

$$I_1 = \int_{\omega_{\min}}^{\omega_{\max}} \nu W_2 \, d\omega/\omega^2, \quad I_2 = \int_{\omega_{\min}}^{\omega_{\max}} \nu W_2 \, d\omega/\omega.$$

These integrals include data from the entire region $M + m_\pi \leq W \leq W_{\max}$ but do not include elastic (p and d) or quasielastic (d) contributions. These integrals, extended to $\omega_{\max} = \infty$, appear in certain sum rules.[14]

Based on the statistical and systematic errors, the inelastic scattering of electrons from neutrons is appreciably smaller than from protons over a wide range of Q^2 and W. This suggests that a significant fraction of the deep inelastic scattering is nondiffractive in character,[15] at least for $x' > 0.1$.

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TABLE II. Integrals over νW_2^p and νW_2^d. Elastic contributions are not included. Terms are defined in the text. Each entry in the table has an estimated systematic error of 5%, which includes systematic uncertainties from interpolation and integration. The purely statistical errors are less than 1%. The systematic error in the ratio of the same integral for p and d is estimated to be 3%.

Q^2 (GeV^2)	$\omega_{\min}$	$\omega_{\max}$	$W_{\max}$ (GeV)	I_1^p	I_1^d	I_2^p	I_2^d
1.0	1.27	25.0	5.0	0.163	0.285	0.809	1.459
1.0	1.27	5.0	2.2	0.113	0.191	0.309	0.524
4.0	1.07	5.0	4.1	0.106	0.173	0.294	0.492

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Pion Diffraction Dissociation in 205-GeV/c π^-p Interactions*

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Pion diffraction dissociation into masses up to approximately 6 GeV is observed in the reaction $\pi^- + p \rightarrow p + X$ at 205 GeV/c. The pion single-diffraction cross section for mass squared ≤ 32 GeV^2 is 1.9 ± 0.2 mb.

Diffraction dissociation of the pion into states of mass $\lesssim 2$ GeV has been established in pion-nucleon experiments at momenta up to 40 GeV/c.[1] We describe here a study of 205-GeV/c π^-p interactions in which the first evidence is presented for diffraction dissociation of pions into substantially higher masses, up to approximately 6 GeV. Many of the features of pion diffrac-