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THE RATIO OF DEEP-INELASTIC e-n TO e-p CROSS SECTIONS IN THE THRESHOLD REGION*

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ABSTRACT

We report measurements of the ratio of the deep-inelastic electron-neutron to electron-proton differential cross sections in the threshold ($\omega < 3$) region. The ratio was found to scale and to decrease monotonically with decreasing ω. No violation of the quark model lower bound of 0.25 was observed in the ratio.

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Previous comparisons[1,2] of deep-inelastic electron-neutron and electron-proton scattering cross sections have shown that the differential cross section ratio σ_n/σ_p decreases with decreasing ω in the threshold ($\omega < 3$) region to a value close to the quark model lower bound[3] of 0.25. We present here results of an experiment which improves the accuracy of σ_n/σ_p in the threshold region and which extends the measurements to lower values of ω.

The apparatus and methods of analysis used were nearly identical to those of an earlier experiment,[1] details of which may be found in references 4 and 5. An electron beam at the Stanford Linear Accelerator Center (SLAC) passed through 14-cm targets of liquid hydrogen or deuterium. Scattered electrons were analyzed by the SLAC 8-GeV spectrometer. Raw hydrogen and deuterium differential cross sections were extracted from the data and radiatively corrected. Cross sections for the scattering of electrons from stationary free neutrons were determined by applying smearing and unsmearing procedures[1,4] to the hydrogen and deuterium data. The smearing corrections were calculated using the method of Atwood and West[6] with small modifications to include off-mass-shell corrections.[7]

Differential cross sections for the scattering of electrons from hydrogen and deuterium were measured at laboratory angles θ of 15^o, 19^o, 26^o, and 34^o. At each angle measurements were made over a range of scattered electron energy E' for several values of incident electron energy E between 8.7 and 20 GeV. The mass W of the unobserved hadronic final state is defined by $W^2 = M^2 + 2M\nu - q^2$, where M is the mass of the proton, $\nu = E - E'$ is the energy transfer, and $q^2 = 4EE' \sin^2 \theta/2$ is the invariant square of the four-momentum transfer. We define the usual scaling variables[8] $x = q^2/2M\nu = 1/\omega$, and $x' = q^2/(q^2 + W^2) = 1/\omega'$. For $W \geq 1.8$ GeV the data lie in the kinematic range $4.9 < q^2 < 20.7\ (\mathrm{GeV}/c)^2$ and $0.31 < x < 0.90$.

The structure functions W_1 and W_2, which can be defined for the proton, neutron, or deuteron, are related to the differential cross sections in the usual form

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_M \left[W_2(q^2, \nu) + 2W_1(q^2, \nu) \tan^2\theta/2\right],$$

where σ_M is the Mott cross section. The ratio of W_2 to W_1 is related to R, the ratio of the cross sections for absorption of longitudinal and transverse virtual photons, by the expression

$$W_2/W_1 = q^2(1 + R)/(q^2 + \nu^2) .$$

We report here on σ_n/σ_p, the ratio of the neutron to proton differential cross sections. Equality of R for the neutron (R_n) and for the proton (R_p), suggested[5,9] by an earlier experiment,[1] would allow interpretation of σ_n/σ_p as the structure function ratio W_{2n}/W_{2p}. Preliminary data from the present experiment also indicate that R_n is consistent with being equal to R_p in the threshold region. Detailed studies of R and the individual structure functions will be reported in future publications.

The W dependence of σ_n/σ_p is shown in Fig. 1 for representative values of x and x'. Ratios for all incident energies were binned in small intervals of $W(\Delta W = 0.2$ GeV) and x or $x'(\Delta x = 0.05$; small corrections were applied to shift the data to the center of each bin). Previous experiments[8] have shown that the proton structure functions show deviations from scaling in x for $W < 2.6$ GeV, but that the scaling region can be extended to lower values of W ($W \geq 1.8$ GeV) by the use of the scaling variable x'. No major deviations from scaling in either x or x' appear in our data for the ratio σ_n/σ_p; i.e., there is no apparent W dependence of σ_n/σ_p for fixed values of x or x'. This result implies that data for $W \geq 1.8$ GeV can be used to determine the x (or x') dependence of σ_n/σ_p over a wide range of x (or x').

Values of σ_n/σ_p as functions of x and x' are given in Table 1 and are shown in Fig. 2. These values were obtained by calculating the ratios at all available kinematic points for $W \geq 1.8$ GeV, and forming weighted averages[10] of these ratios over small intervals in x or x' ($\Delta x = 0.03$). Only random errors (including counting statistics and also charge monitor, target density, and rate dependent fluctuations) are shown in Fig. 2. Most systematic errors in the cross sections (solid angle, E and E' calibration, monitor calibration, etc.) cancel in the ratio σ_n/σ_p. Of those which do not cancel, we estimate systematic uncertainties arising from five sources. Uncertainties in the deuteron elastic and quasielastic radiative tails arising from lack of knowledge of the neutron form factors at large q^2 contribute a small error of about 0.002 to σ_n/σ_p. Uncertainties from the remaining four sources are listed separately in Table 1. The first column gives the experimental error due to the $\pm 1\%$ uncertainty in the ratio of the number of nuclei in the deuterium target to that in the hydrogen target. The other three columns give errors due to uncertainties in the deuterium smearing corrections. The smearing and unsmearing corrections, which were calculated using the Hamada-Johnston[11] wave function, changed the uncorrected σ_n/σ_p ratios by multiplicative factors of 1.08, 1.07, 1.01, 0.91, 0.74, and 0.40 at x values of 0.31, 0.58, 0.67, 0.73, 0.79, and 0.88 respectively. The uncertainty quoted as "wave function" reflects the change in σ_n/σ_p when other reasonable deuteron wave functions[12] are used. The uncertainty quoted as "off-shell" is taken to be the full effect of the off-mass-shell correction[4,7] in the smearing formalism. This correction is such as to reduce σ_n/σ_p. The uncertainty quoted as "fit" reflects the change in σ_n/σ_p when different parametric functions are used to fit the neutron and proton structure functions which enter into the smearing and unsmearing integrals. The choice $R_n = R_p = 0.18$ was used in the process of obtaining the parametric representations[13] of the structure functions. The extracted σ_n/σ_p ratios were insensitive to the choice of R. Glauber corrections are known to be small.[4] Other deuteron corrections cannot be estimated but are expected to be small.

The results of two previous experiments[1,2] are also shown in Fig. 2. The data from each of the previous experiments were rebinned into small x and x' intervals ($\Delta x = 0.03$) as in this experiment. Note that the present experiment used the same spectrometer and a similar analysis as in Ref. 1, whereas a different spectrometer and a different analysis procedure were used in Ref. 2.

The main feature of Fig. 2 is the pronounced decrease of σ_n/σ_p with increasing x. No violation of the quark model lower bound is observed in the ratio. Although the data do not rule out an approach to the quark model lower bound of 0.25 at x = 1, the data exclude the symmetric quark model prediction[14] of 0.67 and make improbable a duality model prediction[15] of 0.47 at x = 1. However, both models can be modified to account for the new data, the former by the inclusion of quark-quark correlations, and the latter by a different assumption about the behavior of the as yet unmeasured neutron elastic form factors at large q^2.

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TABLE CAPTION

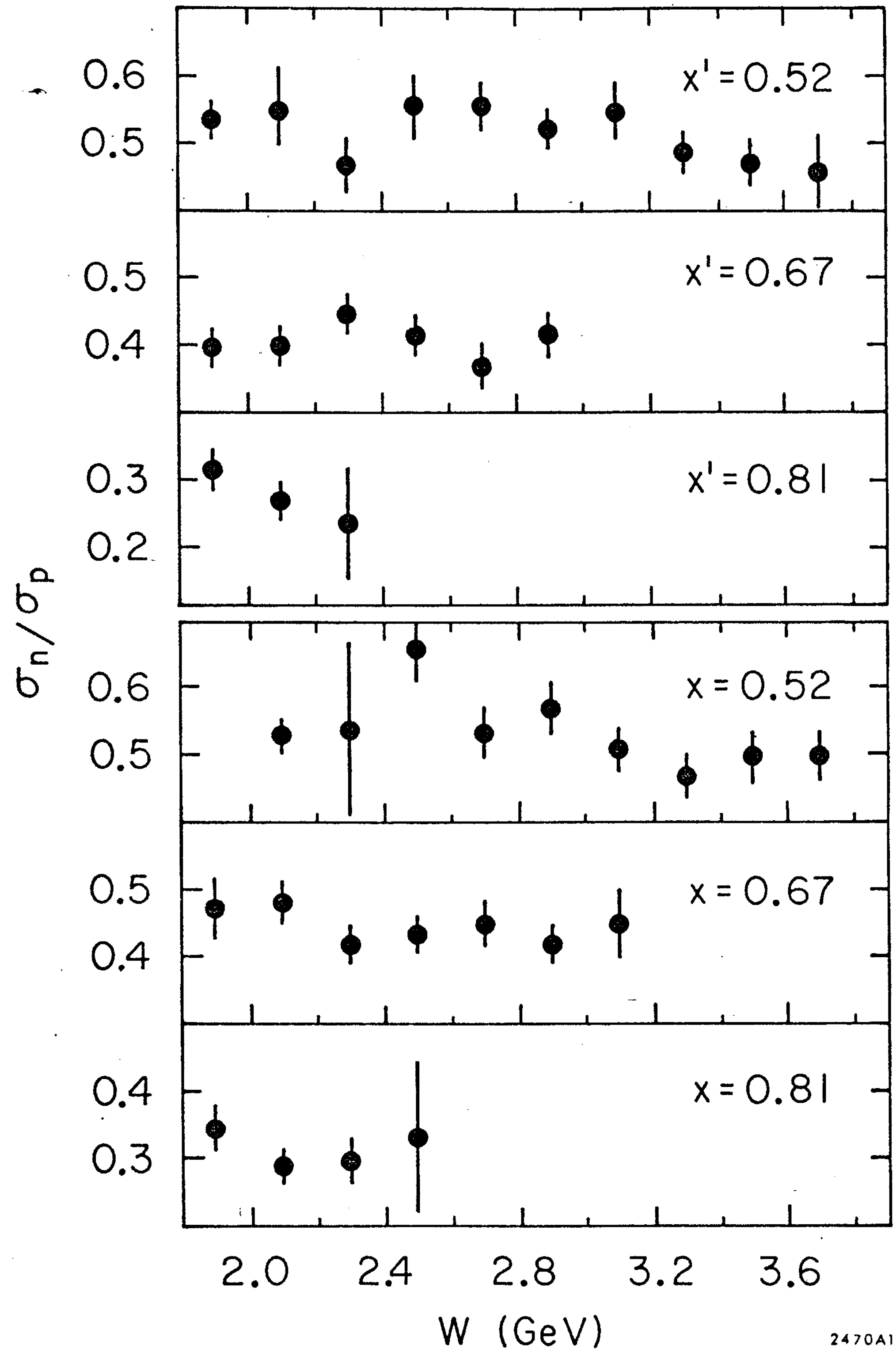
1. σ_n/σ_p (and its random error) as a function of x and x' and some of the absolute systematic uncertainties in σ_n/σ_p as a function of x.

FIGURE CAPTIONS

1. Representative plots of σ_n/σ_p for fixed x or x' ($\Delta x = 0.05$) as a function of W($\Delta W = 0.2$ GeV). Only random errors are shown.
2. σ_n/σ_p versus x and x' (only random errors are shown). All data for $w \geq 1.8$ GeV are included. The 18°, 26°, and 34° data are from the MIT-SLAC experiment of Bodek et al. (Ref.1). The 6° and 10° data are from the SLAC-MIT experiment of Poucher et al. (Ref. 2). The data from the present experiment were taken at 15°, 19°, 26°, and 34°.

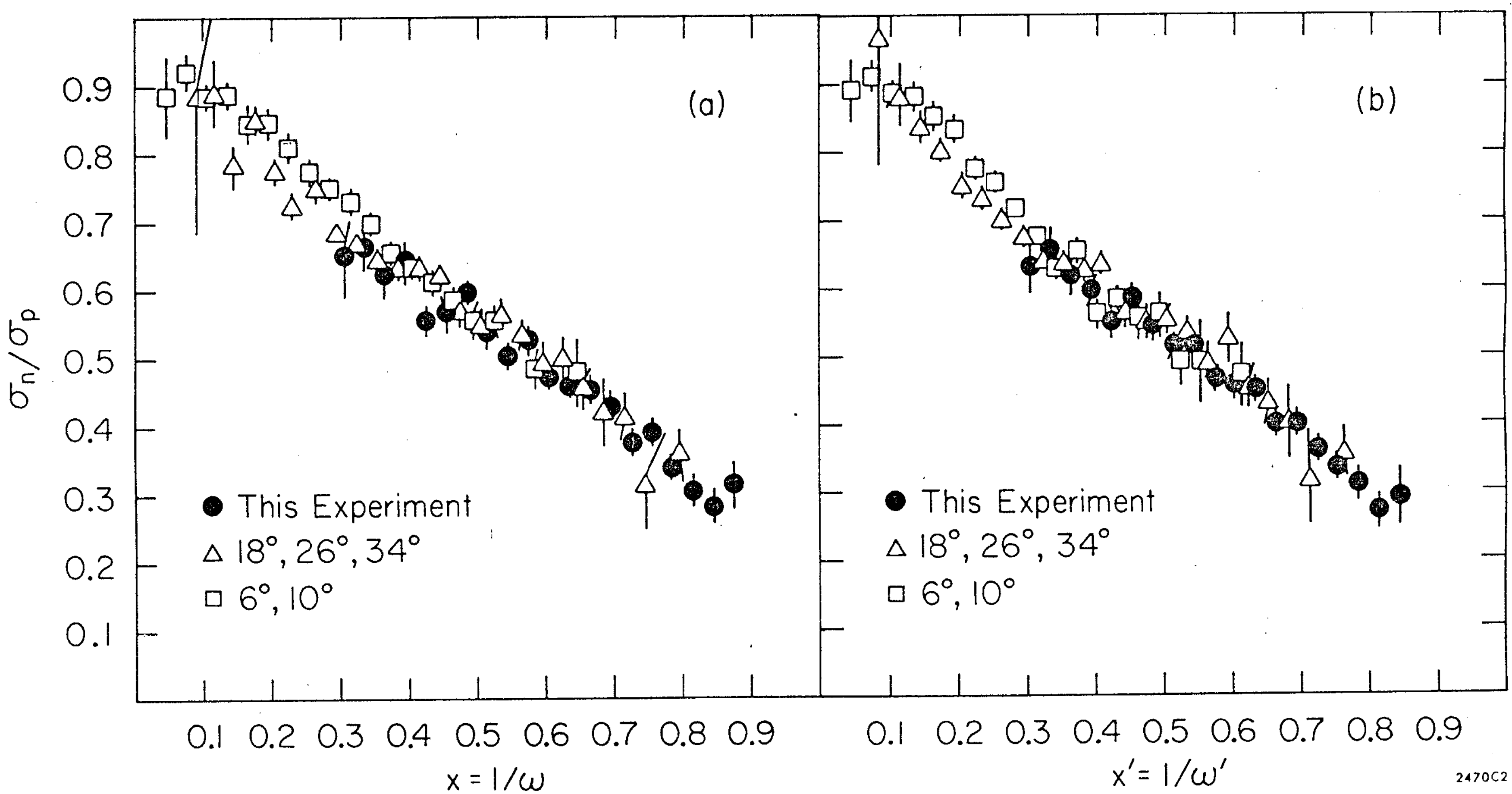
TABLE 1

x	σ_n/σ_p	Systematic Uncertainties				x'	σ_n/σ_p
		Target	"Wave Function"	"Off Shell"	"Fit"		
0.305	0.647 ± 0.058	0.017	0.001	0.001	0.000	0.305	0.631 ± 0.038
0.335	0.663 ± 0.033	0.017	0.002	0.001	0.000	0.335	0.656 ± 0.031
0.365	0.620 ± 0.031	0.016	0.002	0.001	0.000	0.365	0.618 ± 0.031
0.395	0.643 ± 0.032	0.016	0.002	0.002	0.000	0.395	0.596 ± 0.028
0.425	0.555 ± 0.026	0.016	0.003	0.002	0.000	0.425	0.548 ± 0.023
0.455	0.565 ± 0.022	0.016	0.004	0.002	0.000	0.455	0.585 ± 0.021
0.485	0.594 ± 0.023	0.016	0.004	0.003	0.000	0.485	0.542 ± 0.020
0.515	0.536 ± 0.022	0.016	0.005	0.004	0.000	0.515	0.514 ± 0.020
0.545	0.503 ± 0.020	0.015	0.005	0.004	0.000	0.545	0.515 ± 0.020
0.575	0.524 ± 0.020	0.015	0.006	0.004	0.000	0.575	0.465 ± 0.019
0.605	0.473 ± 0.019	0.015	0.006	0.005	0.000	0.605	0.454 ± 0.019
0.635	0.460 ± 0.019	0.015	0.007	0.006	0.000	0.635	0.451 ± 0.020
0.665	0.454 ± 0.021	0.015	0.008	0.007	0.001	0.665	0.398 ± 0.019
0.695	0.431 ± 0.020	0.014	0.010	0.008	0.002	0.695	0.399 ± 0.021
0.725	0.376 ± 0.020	0.014	0.012	0.009	0.004	0.725	0.362 ± 0.020
0.755	0.391 ± 0.021	0.013	0.014	0.010	0.007	0.755	0.335 ± 0.023
0.785	0.337 ± 0.020	0.013	0.015	0.011	0.012	0.785	0.310 ± 0.024
0.815	0.304 ± 0.024	0.012	0.016	0.012	0.014	0.815	0.270 ± 0.026
0.845	0.281 ± 0.025	0.012	0.018	0.014	0.017	0.845	0.291 ± 0.041
0.875	0.313 ± 0.034	0.012	0.020	0.017	0.020	-----	----- -----



x' = 0.52
x' = 0.67
x' = 0.81
x = 0.52
x = 0.67
x = 0.81
σ_n/σ_p
0.6
0.5
0.4
0.3
0.2
2.0
2.4
2.8
3.2
3.6
W (GeV)
2470A1

Fig. 1



(a)
(b)
σ_n/σ_p
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
This Experiment
18°, 26°, 34°
6°, 10°
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
x = 1/ω
x′ = 1/ω′
2470C2

Fig. 2