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Experimental Results on Scaling and the Neutron to Proton Cross Section Ratio in Deep Inelastic Electron Scattering

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ABSTRACT

A review of present knowledge about the scaling of the neutron and proton structure functions and about the neutron to proton cross section ratio is presented. Emphasis is placed on the results of a recent electron scattering experiment at SLAC from which neutron cross sections were extracted from deuterium data using an impulse approximation.

The discovery of scaling[1] in deep inelastic electron proton scattering resulted in the formulation of a number of theoretical models explaining the experimental data. Additional measurements[2-5] have established that the neutron exhibits scaling, but that the neutron cross sections are different from the proton cross sections. The study of the comparison of neutron and proton cross sections provide valuable tests of those nucleon structure models.

In this presentation, we will review some of the experimental evidence for scaling in deep inelastic electron scattering. Emphasis will be placed on the results of a recent electron scattering experiment at SLAC[2] in which e-p and e-n cross sections were compared. A detailed discussion of the apparatus used in these electron scattering experiments can be found in Refs. 1-6. Briefly, an electron beam of energy E is incident on a liquid hydrogen or liquid deuterium target. Scattered electrons are detected by a magnetic spectrometer. The cross section $d^2\sigma/d\Omega dE'$ is measured for several scattering angles Θ and various initial and final electron energies E and E'.

In the one photon exchange approximation, the cross section is represented by two structure functions W_1 and W_2.

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

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where

$$\sigma_M = \frac{\alpha^2 \cos^2\frac{\theta}{2}}{4E^2 \sin^4\frac{\theta}{2}}, \quad \nu = E - E', \quad q^2 = 4EE' \sin^2\frac{\theta}{2}$$

The mass of the final hadronic state W is defined by $W^2 = M^2 + 2M\nu - q^2$ where M is the nucleon mass.

An alternate way of describing the cross section is in terms of cross sections for transverse and scalar virtual photons, σ_t and σ_s. The electron's kinematics determine the flux Γ, polarization ϵ, and effective momentum K of the virtual photon.

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma\,(\sigma_t + \epsilon\sigma_s)$$

$$\Gamma = \frac{\alpha K E' 2}{4\pi^2 q^2 E(1-\epsilon)}, \quad K = \frac{W^2 - M^2}{2M}, \quad \epsilon = \frac{1}{1 + 2\tan^2\frac{\theta}{2}\left(1 + \frac{\nu^2}{q^2}\right)}$$

Experimental separation of W_1 and W_2 is possible if data is taken at several angles for the same ν and q^2. The separated structure functions are usually given in terms of W_2 and $R = \sigma_s/\sigma_t = W_2/W_1\left(1 + \frac{\nu^2}{q^2}\right) - 1$

Earlier determinations[6] of R for the proton, R_p, have established that it is consistent with being a constant over the region where it was measured ($2 < W < 4$ GeV, $1.5 < q^2 < 11$ $[\text{GeV}/c]^2$). The quoted average value was 0.18 ± 0.10[6]. The assumption that R_p has this value elsewhere allowed the determination of νW_2^p over a wider kinematic range ($2 < W < 5$ GeV, $1.0 < q^2 < 20$ $[\text{GeV}/c]^2$). νW_2^p was found to be consistent with being a function of the single variable $\omega = 2M\nu/q^2$ over that wider kinematic range if only data for which W was greater than 2.6 GeV were included. If data for $W < 2$ GeV were also included, then νW_2^p was better represented by a function of the single variable $\omega' = \omega + M^2/q^2$.

Our analysis of data from the recent electron scattering experiment[2] and of data from an earlier small angle experiment[5] has yielded better determinations of R_p, and the first determinations of R for the neutron and the deuteron, R_n and R_d, respectively. R determinations were made for the range $3 < \nu < 12$ GeV and $0.5 < q^2 < 16$ $[\text{GeV}/c]^2$. The great bulk of the R values lie in the range 0.05 to 0.40. We also see indications of a possible kinematic dependence in R_p; a detailed discussion can be found in Ref. 4. We obtain an average value for R_p of 0.168 ± 0.074 in agreement with previous results. We also find that R_d is consistent with being equal to R_p with the average difference $R_d - R_p = -0.005 \pm 0.043$. As is shown in Ref. 3, the equality $R_p = R_d$ implies $R_p = R_n$.

We investigated the scaling behavior of the structure functions νW_2 and $2MW_1$ for the proton and the deuteron without making any assumptions about R, as both W_1 and W_2 were extracted from the data in the region where measurements from several angles were available. The error in the value of R extracted from each separation point was propagated into the errors in W_1 and W_2. Interpolated values of cross sections were employed in order to study the q^2 behavior of νW_2 and $2MW_1$ for several contours of constant values of ω. Plots of νW_2^p vs q^2 for a few selected values of ω are shown in Fig. 1; similar behavior is observed for $2MW_1^p$. Only $W > 2$ GeV data were used. Exact scaling in ω would require that νW_2^p be constant in q^2 for fixed ω. Our data indicate that small deviations from scaling in ω occur in the form of a slow fall-off in the value of νW_2^p with q^2 for $q^2 > 1.0$ $[\text{GeV}/c]^2$. An alternate way of looking at the data says that we observe approximate scaling in ω at around $q^2 = 1\ [\mathrm{GeV}/c]^2$ and that exact scaling might gradually set in at higher q^2 We have made least square fits of the form $2MW_1{}^P = a_1(1+b_1q^2)$ and $\nu W_2{}^P = a_2(1+b_2q^2)$ to the structure functions at each fixed ω contour. In the region $1.5 \leqslant \omega \leqslant 3.0$ we find average values $b_1 = -0.033 \pm 0.004\ [\mathrm{GeV}/c]^{-2}$ and $b_2 = -0.026 \pm 0.003\ [\mathrm{GeV}/c]^{-2}$. Similar values are obtained for fits to the deuteron structure functions. The above values for b_1 and b_2 shift by less than the quoted statistical error if the constraint $W > 2.6$ GeV is imposed. Chanowitz and Drell[7] have suggested that a fall-off of $\nu W_2{}^P$ and $2MW_1{}^P$ with increasing q^2 may be interpreted as evidence of structure of possible nucleon constituents. For gluons of mass M_g the fall-off will take the form $\nu W_2{}^P = F(\omega)[1-2q^2/M_g{}^2]$. Our data indicate a value of $M_g{}^2$ in the range 60-75 GeV^2 with a statistical error of about 10 GeV^2.

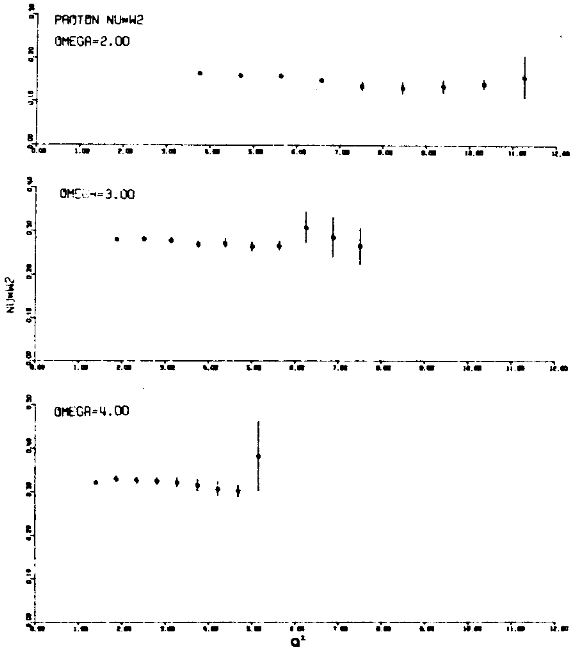

Fig. 1 $\nu W_2{}^P$ vs q^2 for fixed ω.

A similar study was done to test scaling in ω'[8]. We have performed fits of the form $2MW_1 = g_1(\omega')(1+C_1q^2)$ and $\nu W_2 = g_2(\omega')(1+C_2q^2)$. We find C_1 and C_2 consistent with zero for the range $1.5 \leqslant \omega \leqslant 3.0$.

We conclude that an analysis of our data when no assumptions are made about R shows that νW_2 and $2MW_1$ display a statistically significant deviation from scaling in ω for $q^2 > 1\ [\mathrm{GeV}/c]^2$. A slope of νW_2 vs q^2 at constant ω could be interpreted as evidence for scaling breaking either at high q^2 ($q^2 \simeq 10\ [\mathrm{GeV}/c]^2$) or at low q^2 ($q^2 \simeq 1\ [\mathrm{GeV}/c]^2$). The indication that structure functions scale well in the variable ω' tends to support the latter view. A similar study for the range $\omega > 4$ could in principle distinguish between the two alternatives, but the range of q^2 for our data for $\omega > 4$ is too small for any significant scaling study.

The ratio of the neutron and proton cross sections[2] is shown in Fig. 2(a) as a function of the variable $x = 1/\omega$. Neutron cross sections were obtained from deuterium data using an impulse approximation[3,9]. Similarly, the difference between the proton and neutron structure functions $\nu W_2{}^P - \nu W_2{}^n$ is shown in Fig. 2(b). Within the errors, the neutron structure functions display a similar kind of scaling behavior as is seen in the proton data[3,4]. The neutron cross section is smaller than the proton cross section at small ω, indicating a significant non-diffractive component in the virtual photon-nucleon interaction. The small ratio at small ω cannot be explained in terms of a simple quark gluon model. Quark-quark correlations must be included in the model in order to explain the experimental results.

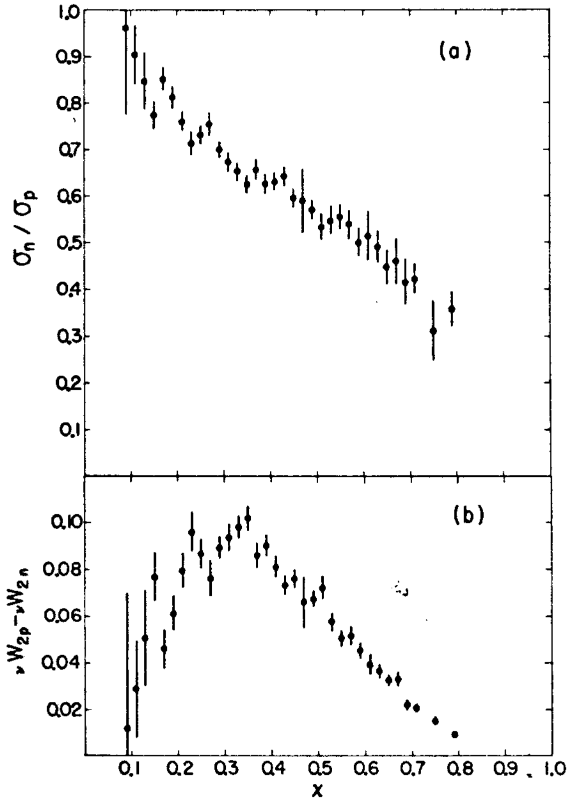

Fig. 2(a) σ_n/σ_p vs $x = 1/\omega$.
2(b) $\nu(W_2{}^p - W_2{}^n)$ vs x, with the assumption $R_p = R_n = 0.18$. The errors shown are statistical only.

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