Sec. 2.4 Deep Inelastic Scattering

MEASUREMENT OF THE INTERNAL SPIN
STRUCTURE OF THE PROTON

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ABSTRACT

Our final results of measurements at SLAC of the spin dependent
asymmetry in the deep inelastic scattering of longitudinally polarized
electrons by longitudinally polarized protons are presented. Data
were obtained at a scattering angle of 10° and for incident energies
of 16.2 and 22.7 GeV, which cover the kinematic range 0.18<\(x\)<0.70 and
3.5<\(Q^2\)<10.0 (GeV/c)². We compare our results with various models of
proton spin structure and with the Bjorken and Ellis-Jaffe sum rules.

EXPERIMENT

Inclusive deep inelastic electron proton (and electron neutron)
scattering is described by four independent structure functions. Two
of these are spin dependent and can be determined only from measure-
ments of the scattering of polarized electrons by polarized nucleons;
indeed thus far the only information about them comes from our SLAC
experiments. Knowledge of these spin dependent structure functions
is important¹,²,³ for tests of the parton model, of models of nucleon
structure, of the Bjorken polarization sum rule, and of QCD, and also
is essential for an understanding of spin effects in high energy
hadron-hadron scattering.

The method of the experiment has been described.⁴ The polarized
electron source⁵ (PEGGY I), which is based on photoionization of
electron-spin-polarized \(^6\)Li atoms, provided 5x10⁶e⁻/pulse at 120 pps
with a polarization of 0.80±0.03. The polarized target, which was
based on the method of dynamic nuclear polarization⁶,⁶, consisted of
butanol doped with porphyrin oxide and provided an average proton
polarization of 0.60. The spectrometer (Fig. 1) consisted of two
dipole magnets, a Cerenkov counter, a PWC system, p and \(\theta\) hodoscopes,
and a 20 radiation length segmented lead glass shower counter. The
momentum acceptance \(\Delta p/p_0\) (overall \(\Delta\Delta p/p_0\)) was 0.4 (-0.4 msr),
and the accuracy of the momentum determination was better than 1%. The
spectrometer was designed to detect electrons scattered vertically
by \(\theta=10^\circ\).
The basic quantity measured was the intrinsic electron-proton asymmetry $A = (d\sigma(+) - d\sigma(-))/(d\sigma(+) + d\sigma(-))$. From $A$ we determine the virtual photon-proton helicity asymmetry $A_1 = (\sigma_1 - \sigma_3/2)/(\sigma_1 + \sigma_3/2)$ using the relation $A = D(A_1 + \eta A_2)$ where $A_2$ is an interference term, $\eta$ and $D$ are known kinematic expressions. Half a million events were collected at each of two spectrometer settings with $E(E') = 22.66(11.5)$ GeV and $E(E') = 16.19(10.0)$ GeV.

RESULTS

Analysis of the data is complete, including radiative corrections. Fig. 2 shows values of $A/D = A_1$ obtained from experiments E-80 and E-130 plotted vs. $Q^2$ in three intervals of $x$. The error bars include statistical and systematic errors. To test scaling of $A_1$ the values of $A/D$ have been divided by $\sqrt{x}$ (which described well the $x$ dependence of our $Q^2$-combined data) and least-squares straight lines have been fit in the region $Q^2 \sim 2$ GeV$^2$. The assumption of scaling (zero slope) gives $\chi^2$/DOF of 0.43/5, 2.4/5 and 5/3 and confidence levels of 99%, 80% and 18%, for the top, middle and bottom boxes, respectively. We therefore conclude that scaling of $A_1$ holds within our errors.

The $Q^2$-combined values of $A/D$ are shown in Fig. 3. Our data are best described by $A/D = (0.94\pm0.08)/\sqrt{x}$ (with $\chi^2$/DOF=9.5/11) and are consistent only with the Carlitz/Kaur, the Schwinger and possibly the Close models of $A_1$. Our confidence levels in these models are 70%, 70%, and 3%, respectively.

Our data permit a test of the Ellis-Jaffe sum rule$^7$ for the proton:

$$S_{EJ}^P = 2 \int_0^1 g_1^P dx \frac{1}{x} \frac{1}{1+R^P} \frac{A_{12}^P}{3} \frac{|g_A^P|}{|g_V^P|} = 0.372 \pm 0.002$$

and of the Bjorken sum rule$^8$:

$$S_{BJ}^P = 2 \int_0^1 (g_1^P - g_1^N) dx \frac{1}{x} \frac{1}{1+R^P} \left( \frac{A_{12}^P}{3} - \frac{g_A^N}{3} \right) \frac{|g_A^P|}{|g_V^P|} = 0.418 \pm 0.002$$

if $A_1^N$ is approximated by zero. The integrand $A_{12}^P/(1+R^P)$ is plotted in Fig. 4 using $F_2^P(x,Q^2)$ from available data$^9$ and the value $R=0.25\pm0.10$ from the SLAC ep data.$^{10}$ The smooth curve in the region $0.1<x<0.64$ is obtained from our fit $A_1=0.94/\sqrt{x}$ and $F_2^P$ evaluated at $Q^2=4$ (GeV/c)$^2$ (which is the mean $Q^2$ value of our data). The integral under this curve in the data region $0.1<x<0.64$ is 0.189\pm0.016, which saturates 45% of the Bjorken sum rule. The integral over the full $x$ range using the Regge theory prediction $A_1 \propto x^{1.14}$ for $x<0.01$ and our fit $A_1=0.94/\sqrt{x}$ for $x>0.1$ gives

$$2 \int_0^1 g_1^P(x) dx = 0.33 \pm 0.10$$

In conclusion, our result is consistent with the Ellis-Jaffe sum rule for the proton. This implies that our results are also consistent with the Bjorken sum rule provided that the neutron contribution is as small as suggested by the Ellis-Jaffe sum rule for the neutron.

It would clearly be valuable to measure $A_1^N$ for the neutron and also the other structure function $A_2$ for both the proton and the neutron. Use of a polarized deuterium target as well as a polarized
Fig. 1: E-130 Spectrometer (Plan View)

Fig. 2: Radiatively corrected values of $A/D = A_1$ obtained in SLAC E80 (open diamonds) and SLAC E130 (closed squares)

Fig. 3: Experimental Values $A_1$ Compared with Theories.
2. Current Quarks (Close, 1974).  
5. MIT Bag Model (Jaffe, Hughes, 1977).  

Fig. 4: Experimental values of $A_{1pP}^{Pp}/(1 + R^p)$. $F_2^P$ and $R$ are from unpolarized data. The smooth curve is obtained using $A_1^p(x) = 0.94 \sqrt{x}$. 

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**Fig. 1**

**Fig. 2**

**Fig. 3**

**Fig. 4**
proton target allows for the determination of the neutron structure functions. To determine $A_2$ the nucleon polarization must be transverse to the momentum and spin directions of the incident electron and lie in the scattering plane. We have designed an experiment for SLAC using irradiated NH$_3$ and ND$_3$ targets as well as operation of our polarized target at 5T/0.6K, which is capable of determining $A_1^N$, $A_2^N$, and $A_2^N$ with accuracies about the same as those presented in this paper for $A_1^N$.

The research was supported in part by the U.S. Department of Energy, by the German Federal Ministry of Research and Technology, by the Tokyo Rayon Science Foundation, and by the Ministry of Education, Science and Culture of Japan, and by the University of Tsukuba.

REFERENCES

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