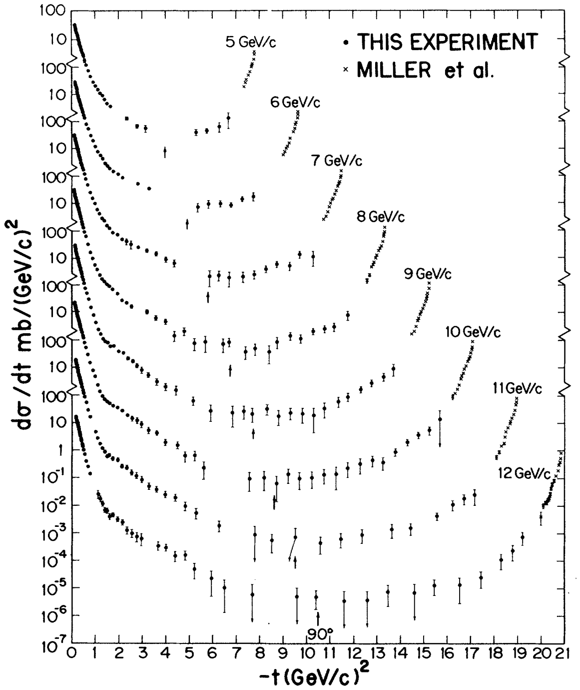

FIG. 2. Neutron-proton differential cross sections. The † indicates the position of 90° in the c.m. systems.

The data show a nearly exponential diffraction peak with the onset of a shoulder at $-t \sim 1.5$ (GeV/c)^2 for momenta above 7 GeV/c. This structure becomes more pronounced as the energy increases and eventually becomes the dip observed in p-p data above 100 GeV/c. We see evidence for additional structure at lower $|t|$ with a steepening of the logarithmic slope for $|t| \lesssim 0.18$ (GeV/c)^2. At large $|t|$ the cross sections flatten and reach a minimum near 90° in the c.m. system where the differential cross section is 4.28 μb/(GeV/c)^2 at 5 GeV/c and 4.3 nb/(GeV/c)^2 at 12 GeV/c. In the backward direction the cross sections rise monotonically and join smoothly with the charge-exchange data of Miller *et al.*[2] Our results are compared with available p-p data and with theory in the following Letter.[6]

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Comparison of Neutron-Proton Elastic-Scattering Data with Theory*

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We examine some features of neutron-proton elastic-scattering data over the laboratory momentum range 4.5 to 12.5 GeV/c. Comparisons with proton-proton elastic scattering data and with theory are made in both the small- and the large-angle–scattering regions.

In the preceding Letter[1] we have reported new data on neutron-proton elastic scattering covering an angular range extending to about 145° in the c.m. system over a laboratory momentum range of 4.5 to 12.5 GeV/c. We discuss here some special features of that data at both small and large scattering angles and make comparisons with proton-proton data and with theory.

Recently there has been a great deal of interest in large-transverse-momentum processes.[2] It is believed that at large momentum transfers the pointlike or constituent structure of hadrons becomes important and the main contribution to the differential cross section is due to the basic quark interaction. The additive quark model, for example, assumes that large-$|t|$ collisions between two hadrons result from the collisions between two constituent quarks whose interaction is indepen-

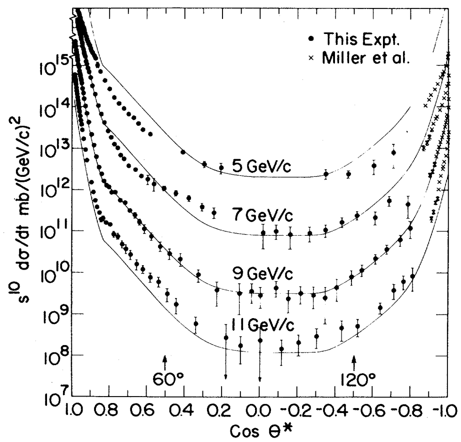

FIG. 1. Comparison of the quark-counting-rule prediction [Eq. (1)] for the energy dependence of large-angle n-p elastic scattering with data from this experiment and E. L. Miller *et al.*, Phys. Rev. Lett. 26, 984 (1971). The *same* smooth curve, fitted by hand to the 9-GeV/c data, is drawn through the data at each momentum to facilitate comparison.

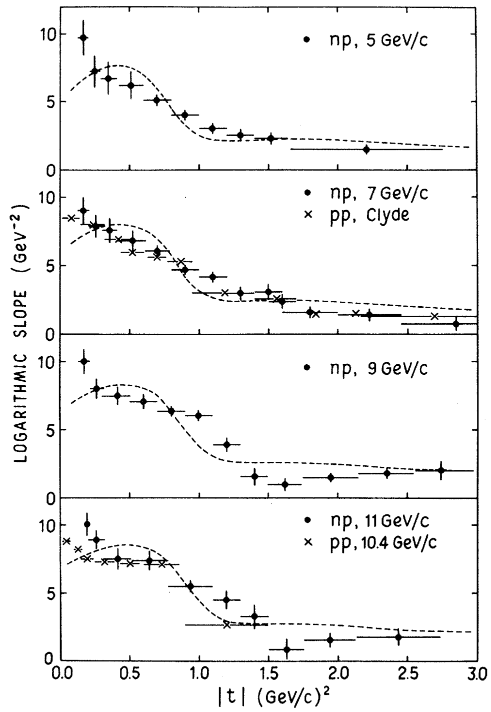

FIG. 2. The t dependence of the logarithmic slope for n-p and p-p data. The 7-GeV/c p-p data are from A. R. Clyde, Lawrence Radiation Laboratory Report No. UCRL 16275, 1966 (unpublished). The dashed curve is the prediction of the global absorption model of Kane and Seidl (Ref. 9).

dent of the presence of the other constituents. This model leads to simple rules which correlate the energy dependence of the differential cross section at fixed large scattering angles with the number of constituent quarks n_i in the interacting hadrons,

$$d\sigma(AB\rightarrow CD)/dt \sim s^{-(n_a+n_b+n_c+n_d-2)}f(\theta^*), \qquad (1)$$

where $n=3$ for baryons and $n=2$ for mesons. Hence, for the n-p elastic reaction we would expect the cross section to fall as s^{-10} at large scattering angles. In Fig. 1 we have plotted $s^{10}d\sigma/dt$ vs $\cos\theta^*$ for our data for several incident momenta. The *same* smooth curve, which was fitted by hand to the 9-GeV/c data, has been drawn on each set of data to facilitate comparison of the data for different momenta. We find that the data are in reasonable agreement with an $s^{-10}f(\theta^*)$ dependence, provided that θ^* is restricted to be close to 90°. However, it is interesting to note that Hojvat and Orear[3] have found an $s^{-6.6}$ dependence in analyzing p-p data from the CERN intersecting storage rings (ISR) and Fermilab at $\theta^*\sim 4.85°$. We have fitted our 90° data and previous n-p data of Perl *et al.*[4] with $s>10$ GeV^2 by an s^{-n} dependence. We obtain $n=10.40\pm0.34$ with χ^2 per degree of freedom of 2.41 for the n-p data. For p-p data at 90°, $n=9.81\pm0.05$ with χ^2 per degree of freedom equal to 13.7.[5] Hence, at 90° in the c.m. system both results are consistent with the prediction of the additive quark model. If we fit our 60° and 120° data by an $s^{-n(\theta^*)}$ dependence, however, we obtain $n(60°)=8.04\pm0.15$ and $n(120°)=8.1\pm0.22$.

Traditionally, elastic-scattering data in the diffraction region have been parametrized by $d\sigma/dt=Ae^{Bt}$, with the interpretation that the logarithmic slope B is a measure of the interaction radius, $R=2\sqrt{B}$. This parametrization was adequate as long as the fit was restricted to a small region in $|t|$, typically $0.2\leq -t\leq 0.5$ (GeV/c)^2. Carrigan[6] suggested that there may be evidence for additional structure and a steepening of the slope for $-t<0.2$ (GeV/c)^2. This apparent change in slope was first seen clearly in p-p data[7] from the ISR at $|t|\sim 0.14$ (GeV/c)^2. This effect is also seen at lower energy in recent p-p data[8] from Stanford Linear Accelerator Center at 10.4 GeV/c, but at slightly higher $|t|$. The high statistics in our n-p data at small $|t|$ made it possible to fit the logarithmic slope over small intervals in $|t|$. In Fig. 2 is plotted the logarithmic slope parameter vs $|t|$ for our data and p-p data. We observe a steepening of the slope at $|t|\sim 0.18$ (GeV/c)^2. Our data, along with the 10.4-GeV/c p-p data from Stanford Linear Accelerator Center, show that this small-

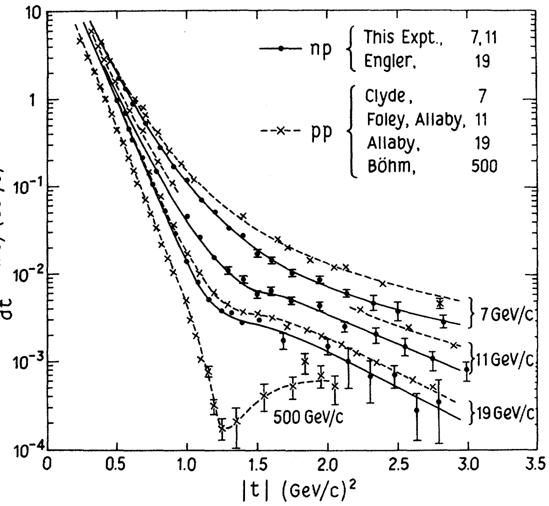

FIG. 3. Development of the dip at $|t| \sim 1.3$ (GeV/c)^2 and comparison of neutron-proton and proton-proton data. The n-p data at 19 GeV/c are from J. Engler *et al.*, Nucl. Phys. B62, 160 (1973). The p-p data at 7 GeV/c are from Clyde, see Fig. 2 caption; at 11 GeV/c, from K. J. Foley *et al.*, Phys. Rev. Lett. 15, 45 (1965), and J. V. Allaby *et al.*, Phys. Lett. 27B, 49 (1968); at 19 GeV/c, from J. V. Allaby *et al.*, Phys. Lett. 28B, 67 (1968); and at 500 GeV/c, from Böhm, Ref. 10. The curves are hand drawn to guide the eye.

$|t|$ structure occurs not only at energies greater than 100 GeV but is also present at lower energies. The dashed curves in Fig. 2 are the prediction of the global absorption model of Kane and Seidl.[9] Their model describes the data reasonably well for $0.2 < -t < 1.5$ (GeV/c)^2; however it does not reproduce the increase in B shown by the data at smaller $|t|$.

Figure 2 also shows a gradual decrease in slope with increasing $|t|$ until $|t| \cong 1.5$ (GeV/c)^2, after which it flattens out. This behavior is most pronounced at the higher momenta where the data suggest a minimum in the slope near $|t| = 1.6$ (GeV/c)^2. This break in slope gradually develops into a pronounced minimum in the cross section observed near $|t| = 1.4$ (GeV/c)^2 in the CERN ISR data.[10] Figure 3 shows the development of the dip and a comparison of n-p and p-p data for $|t| < 3.0$ (GeV/c)^2. Unfortunately, little p-p or n-p data of sufficient accuracy to show the evolution of the dip exist between our highest and the lowest ISR momenta (≈ 400 GeV/c).

As can be seen from Fig. 3, the n-p and p-p cross sections are approximately equal for $|t| < 0.6$ (GeV/c)^2, but the n-p cross section falls faster and for $|t| > 1.5$ (GeV/c)^2 the p-p cross

TABLE I. The n-p differential cross sections and the ratio of n-p and p-p data at 90° in the c.m. system. The σ_{np} are averages of several points about 90°.

Momentum (GeV/c)	$\sigma_{np}(90°)$ [μb/(GeV/c)^2]	$R = \sigma(n\text{-}p)/\sigma(p\text{-}p)$ ($\theta^* = 90°$)
5.0	4.28 ± 1.0	0.29 ± 0.14
6.0	0.94 ± 0.22	0.30 ± 0.07
7.0	0.23 ± 0.054	0.33 ± 0.08
8.0	0.069 ± 0.012	0.34 ± 0.06
9.0	0.025 ± 0.0055	0.37 ± 0.08
10.0	0.01 ± 0.0028	0.29 ± 0.08
11.0	0.0058 ± 0.0018	0.31 ± 0.1
12.0	0.0043 ± 0.0019	0.50 ± 0.22

section is almost twice as large. In terms of a Regge-exchange picture, any difference between n-p and p-p elastic scattering is a result of the isovector exchanges, ρ and A_2, which contribute to the scattering amplitudes with opposite signs. The Kane-Seidl model[9] is able to account qualitatively for the observed t dependence of the n-p and p-p cross-section ratio.

There have been several predictions of the ratio of the n-p to the p-p cross section at 90° in the c.m. system. On the basis of a quark-counting model, Fishbane and Quigg[11] predict $R \equiv \sigma(n\text{-}p)/\sigma(p\text{-}p) = \frac{3}{4}$. Wu and Yang,[12] assuming equal magnitudes for the isospin amplitudes and random relative phases, predict $R = \frac{1}{2}$. Charge independence requires $R \geq \frac{1}{4}$. In Table I we list the values of R obtained from our data and available p-p data.[5] The data are consistent with R being independent of momentum. We obtain for the average over the momentum range 5 to 12 GeV/c, $\bar{R} = 0.34 \pm 0.05$. This rules out the model of Fishbane and Quigg and seems inconsistent with that of Wu and Yang. However, our result is close to the charge-symmetry limit.

We wish to thank G. Kane, R. Cahn, M. Einhorn, and especially J. Luthe for many helpful discussions.

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Measurement of the Magnetic Structure Function of the Deuteron at $q^2 = 1.0\ (\text{GeV}/c)^2$*

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At a square of the momentum transfer of 1.0 $(\text{GeV}/c)^2$ the elastic scattering of electrons on deuterons has been measured at electron scattering angles of 8°, 60°, and 82°. From these data we have extracted a value of $B(q^2) = (0.59 \pm 1.20) \times 10^{-5}$ for the deuteron. This measurement extends the range in momentum transfer by almost a factor of 2 over the previous measurements.

In a previous Letter[1] we have reported on measurements of $A(q^2)$ for the deuteron for q^2 out to 6.0 $(\text{GeV}/c)^2$. $A(q^2)$ is the structure function defined by the one-photon-exchange approximation, $d\sigma/d\Omega = \sigma_{\text{mott}}(A + B\tan^2\frac{1}{2}\theta)$. In this Letter we report on the measurement of $A + B\tan^2\frac{1}{2}\theta$ at scattering angles of 8°, 60°, and 82° for a square of the momentum transfer, q^2, of 1.0 $(\text{GeV}/c)^2$, and extract the deuteron's magnetic structure function B.

The coupling of spin and orbital angular momentum in the deuteron ground state leads to a requirement of 4% D state in $|\psi_d|^2$ in order to explain the deuteron's magnetic dipole moment, from the relation

$$\mu_d = \mu_p + \mu_n - \tfrac{3}{2}P_D(\mu_p + \mu_n - \tfrac{1}{2}). \tag{1}$$

However, N-N phenomenology is generally consistent with $P_D = 6.5 \pm 1.0\%$, which results in a 1.6% deficiency in μ_d compared to experiment. This shortcoming is usually ascribed to very short-range n-p phenomena such as meson-exchange currents, first calculated by Adler and Drell,[2] baryon resonance states in ψ_d, and relativistic corrections. The exchange currents and baryon resonance states are selected to be consistent with the isoscalar ($T = 0$) nature of the deuteron.

Large-angle elastic e-d scattering permits the testing of the dynamics of the deuteron's magnetic dipole moment, and at large q^2 probes the short-distance structure of these nuclear electromagnetic currents. Previous measurements[3,4] of the deuteron's magnetic structure function $B(q^2)$ in the interval $0 \leq q^2 \leq 14\ \text{fm}^{-2}$ (0.55 GeV^2) appear to be fully consistent with calculations using the impulse approximation.[5] These calculations use standard deuteron wave functions from N-N phenomenology and the measured nucleon form factors to compute $B(q^2)$. This approach appears to describe adequately any interaction effects in the deuteron at larger q^2 but leaves unexplained the discrepancy noted above for the static magnetic dipole moment.

Our $A(q^2)$ is measured by scattering electrons at 8°, detecting the electron in the Stanford Linear Accelerator Center (SLAC) 20-GeV/c spectrometer, and detecting, in coincidence with the electron, the deuteron in the SLAC 8-GeV/c spectrometer. The large-angle data were taken at