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TWO FACETS OF THE DEUTERON

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ABSTRACT

Two of the simplest nuclear reactions, electron deuteron elastic scattering and deuteron photodisintegration, will be discussed. In particular, measurements of the tensor analysing power T_{20} in e-d scattering performed with a polarised gas target in the VEPP-3 electron storage ring will be presented. In addition, measurements of deuteron photodisintegration at high energy performed at SLAC will be discussed. The meson-exchange calculations appear to agree well with all available data for electron-deuteron elastic scattering, while the constituent counting rules appear to describe the high-energy deuteron photodisintegration results at $\theta_{cm} = 90°$.

1. Introduction

During the past decade, it was widely believed that electromagnetic probes of the deuteron might reveal the onset of QCD effects in nuclear reactions, since the deuteron is the simplest nucleus and the electromagnetic interaction is the best understood probe of the nucleus. In addition, since the deuteron contains the smallest number of quarks of the nuclei, then the onset of asymptotic scaling might be achieved. I shall discuss two of the simplest nuclear reactions, electron-deuteron elastic scattering at high momentum transfer, and photodisintegration of the deuteron at high energy. In particular, new measurements of tensor polarization at MIT-Bates and analyzing power at Novosibirsk in electron-deuteron scattering will be discussed in light of recent advances in meson-exchange models. In addition, the energy and angular dependence for two-body deuteron photodisintegration at high energy will be discussed in view of data from SLAC.

2. Electron-Deuteron Elastic Scattering

The cross section for electron-deuteron elastic scattering is well known up to a very high momentum transfer. The differential cross section is given by the expression[1]

$$\frac{d\sigma}{d\Omega} = \sigma_M \left[A(Q^2) + B(Q^2)\tan^2\left(\frac{\theta}{2}\right)\right] \quad (1)$$

where σ_M is the Mott cross section, θ is the electron scattering angle, Q is the four-momentum transfer, $A(Q^2)$ and $B(Q^2)$ are related to the monopole

(G_C), quadrupole (G_Q), and magnetic (G_M) form factors of the deuteron by

$$A(Q^2) = G_C^2 + \frac{8}{9}\eta^2 G_Q^2 + \frac{2}{3}\eta\, G_M^2 \tag{2}$$

$$B(Q^2) = \frac{4}{3}\eta\,(1+\eta)\, G_M^2 \tag{3}$$

where $\eta = Q^2/4M_d^2$ and M_d is the mass of the deuteron. Some selected measured values[2-5] for $A(Q^2)$ and $B(Q^2)$ are shown in Fig. 1. The most notable feature is that $B(Q^2)$ exhibits a second maximum near a momentum transfer of 2.5 $(GeV/c)^2$. This feature occurs naturally in a hadronic model of the deuteron, but would be very difficult to describe in terms of a quark model. The three curves shown in Fig. 1 represent the available theoretical calculations[6-8] which simultaneously give the best description of $A(Q^2)$, $B(Q^2)$ and T_{20}, the tensor analyzing power. The calculations of Hummel and Chung et al.[6] and Tjon[7] are relativistic and use the Gari-Krumpelmann form factors of the nucleon. The calculation of

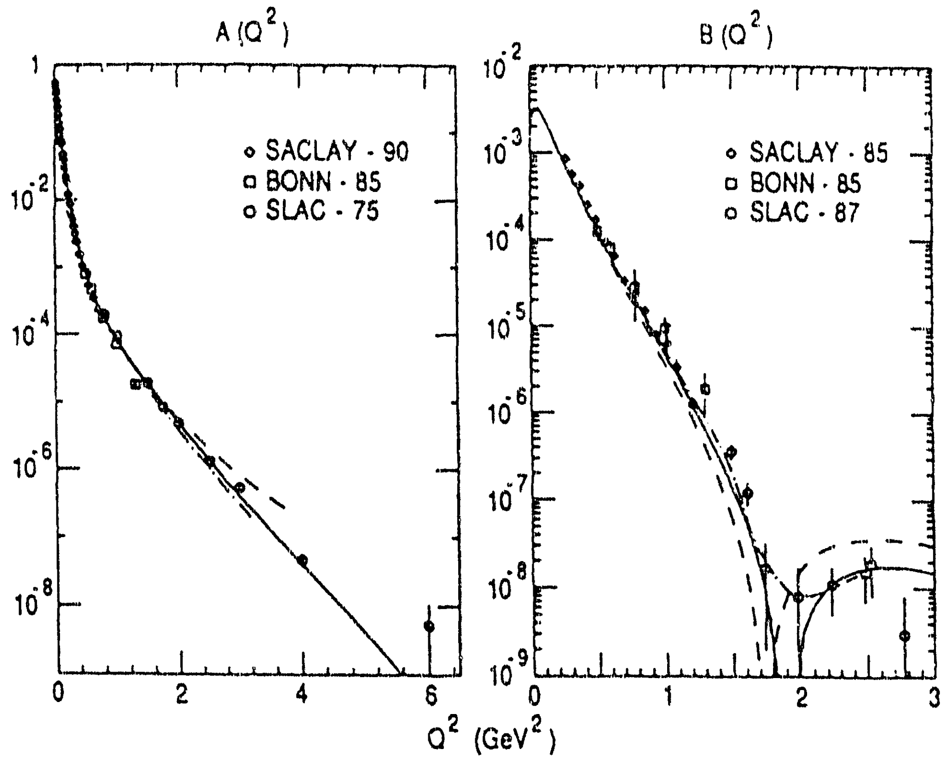

Figure 1. Selected data and theoretical calculations for $A(Q^2)$ and $B(Q^2)$ for electron-deuteron elastic scattering. The three theoretical calculations were selected to give the best overall agreement for $A(Q^2)$, $B(Q^2)$ and T_{20}. The solid curve represents the calculations of Ref. 6, the dashed from Ref. 7 and dash-dot from Ref. 8.

Schiavilla and Riska[8] is nonrelativistic, explicitly includes the pair current and makes use of the Höhler form factors of the nucleon. All three calculations employ the Argonne V14 description of the deuteron. The tensor analyzing power T_{20} is given by

$$T_{20} = -\sqrt{2}\ [X(X+2) + Y/2]/[1+2(X^2+Y)] \qquad (4)$$

in which

$$X = \frac{2}{3}\ \eta(G_Q/G_C),\ \ Y = \frac{1}{3}\ \eta(G_M/G_C)^2[1 + 2(1+\eta)\ \tan^2(\theta/2)] \quad . \qquad (5)$$

Clearly, a measurement of T_{20} will permit the monopole and quadrupole form factors to be deduced.

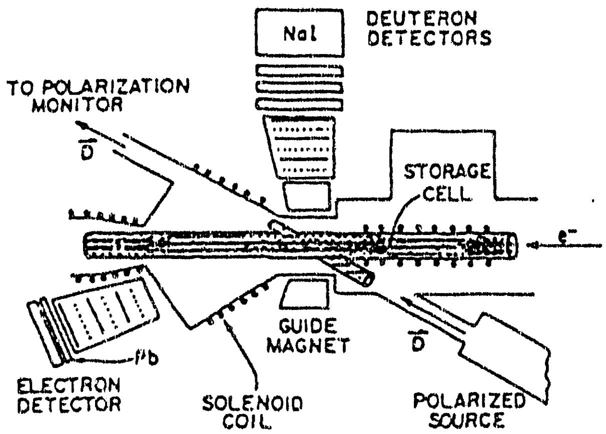

Figure 2. Schematic diagram of the experimental arrangement for measuring T_{20} with an internal polarised deuterium gas target in the VEPP-3 electron storage ring at Novosibirsk. The polarised atoms are injected into a windowless storage cell from an atomic beam source. Only one of the four pairs of electron and deuteron detectors are illustrated.

The recent tensor analyzing power[9] and polarization[10] measurements were performed at Novosibirsk and MIT-Bates, respectively. The experiment at Novosibirsk was a feasibility study conducted as a collaboration between Argonne and Novosibirsk for internal polarized targets in electron storage rings. In particular, a tensor polarized deuterium gas target was contained in a windowless storage cell in the 2-GeV VEPP-3 ring at Novosibirsk. A schematic diagram of the experiment apparatus is shown in Fig. 2. The storage cell consisted of a drifilm coated Aℓ cell which is 94 cm in length and has an elliptical aperture to the electron beam of 46×24 mm. A guide magnetic field is placed around the target to define the axis of quantization and to minimize depolarization induced by the time-varying magnetic field produced by high current pulses of electrons moving through the target. Polarized deuterium atoms from the Novosibirsk atomic beam source[11] were injected into the storage cell. Four nearly identical pairs of electron and deuteron detectors were used to identify the elastic scattering events as described in more detail in Ref. 9. The results for T_{20} from this feasibility study are given by the darkened diamonds in Fig. 3.

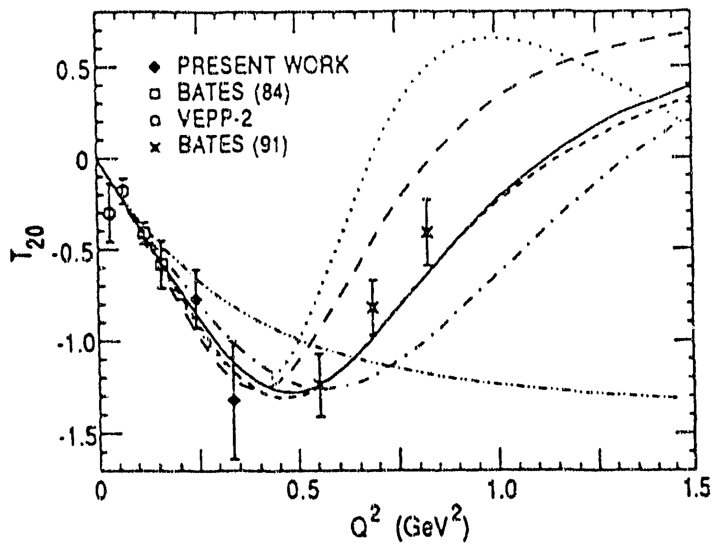

Figure 3. Results for T_{20} as a function of Q^2. The diamonds represent the present results of the phase I internal target feasibility test at Novosibirsk, while open points represent new work from an experiment at Bates in which a recoil deuteron polarimeter was employed. The data at lower Q^2 are from Refs. 12 and 13. The (··—) curve is the simple perturbative QCD model of Carlson, the dotted curve is from Sitarsky et al., while the remaining three curves are the same as those in Fig. 1.

Recent results[10] from an experiment at MIT-Bates are also shown in the figure as crosses. These data were obtained by detecting the tensor polarization t_{20} of the recoiling deuteron in a polarimeter. This experimental arrangement is shown schematically in Fig. 4. Here, the electrons from the Bates Linac impinge on a liquid deuterium target and the scattered electrons are detected in the OHIPS spectrometer, while the recoil deuterons are transported to the polarimeter by a QQDQQQD system. The polarimeter is based on d-p elastic scattering and was calibrated at Saturne II.

Again in Fig. 3, the theoretical calculations[6-8] that simultaneously best describe $A(Q^2)$, $B(Q^2)$ and T_{20} are shown. It is clear that a recently proposed model[13] which is based on perturbative QCD and another[14] which has a high percentage of pre-existing deltas in the deuteron are ruled out by the present data. These curves are given by the dash-dot and dotted curves in the figure.

In order to constrain the theoretical calculations further, it is essential to have better T_{20} results at large momentum transfer and better nucleon form factors, especially G_{E_n} measurements. The ultimate goal of the Novosibirsk work is to produce the highest quality T_{20} data available. In particular, it is expected that the systematic error in the T_{20} measurements

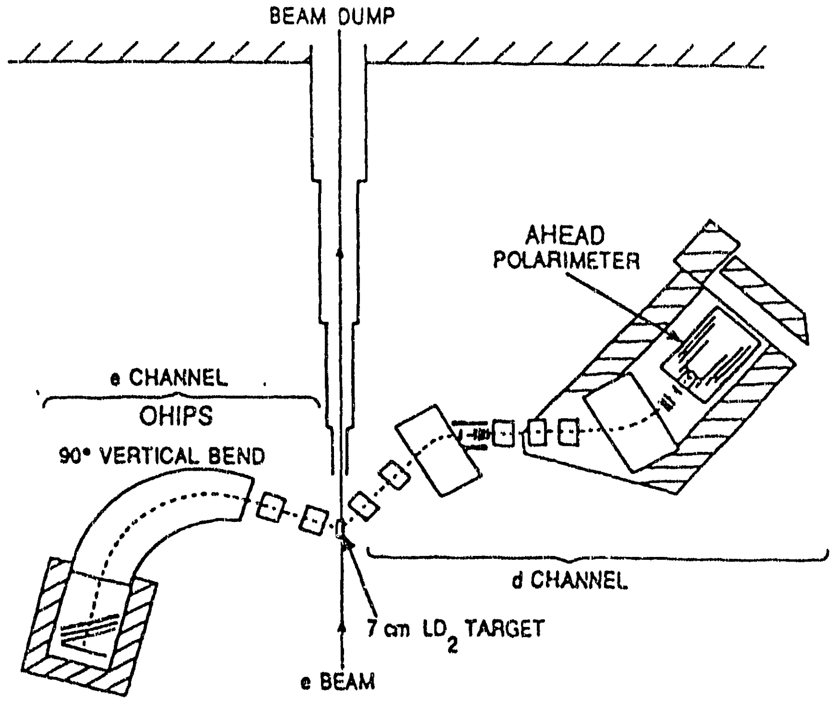

Figure 4. Schematic diagram of the experiment at MIT-Bates to measure t_{20} in e-d scattering where the polarization of the recoil deuterons is measured in the AHEAD polarimeter.

will be only ~5%, as achieved in the feasibility test in Novosibirsk. Since new detectors as well as new targets are required for the next phase of the Novosibirsk experiment, the T_{20} collaboration[16] has grown to include the NIKHEF, LNPI and Tomsk groups.

The next phase of the Novosibirsk experiment which gives approximately a factor of 7 larger target thickness, is in progress. Measurements of the phase 2 target thickness and polarization in the VEPP-3 ring yield 2×10^{12} nuclei/cm^2 and $P_{zz} = 0.55\pm0.17$. At present, background from electrons striking the target cell limit the beam current to 60 mA and collimators are being installed to minimize this background.

The final phase of the internal target work involves replacing the Novosibirsk atomic beam source with the laser-driven source being developed at Argonne. This source is based on spin-exchange optical pumping in a high field and the details have been described elsewhere.[17] In the latest experiment, potassium was optically pumped at 770.1 nm using approximately 2 watts of 770.1-nm light from an Ar-ion pumped Ti-Sapphire laser operating a single mode. The experimental arrangement is shown schematically in Fig. 5. The laser photons passed through a 1/4-wave plate and the central axis of a dipole magnet pole tip before impinging on a dri-film coated[18] pyrex cell. The magnetic field was set to 2.2 kG, in order to permit a rapid and convenient change in frequency from σ_+ to σ_- circularly polarized light, since the level spacing in K at this field is equal to the free spectral range of the intra-cavity thick etalon. Deuterium atoms were injected into the cell from an RF dissociator tube and K was introduced through a small hole in the side of the cell. In the present tests, the K density, determined from a quadrupole mass analyzer, was 8×10^{11} atoms/cm^3, while the deuterium density in the cell was 1.8×10^{14} atoms/cm^3, estimated from a flow of 4.2×10^{17} deuterium atoms/s.

The polarization of the deuterium atoms exiting the transport tube was measured with a permanent sextupole magnet followed by a compression tube with a vacuum gauge as indicated in Fig. 5. The principle of this polarimeter is that the sextupole focuses spin-up atoms and defocuses spin-down atoms. Thus, when the optical-pumping spin-exchange is performed with $\sigma_+(\sigma_-)$ light, one would expect to see a signal in the compression tube detector that corresponds to all (none) of the atoms for 100% deuterium polarization. If the laser light is blocked, the signal would correspond to half of the atoms. The compression tube detector could be scanned across the focus of the sextupole, thereby permitting measurement of the background for ambient atoms and molecules in the vacuum chamber. In order to minimize this background, three differentially pumped vacuum regions were explored. To extract the polarization of the beam it was also necessary to determine the amount of molecular deuterium that entered the compression tube. This was determined by measuring the compression tube signal when the RF dissociator was off and by measuring the molecular fraction, e.e. the ratio of the yield of mass 4 molecules (D_2) with the dissociator on to that with the RF off. The molecular fraction was measured nearly simultaneously with the polarization by passing a small amount of chopped beam from the exit of the transport tube through a quadrupole mass spectrometer (QMS) as indicated in Fig. 5. In the present case, the molecular fraction was found to be 0.25±0.02. The results for a magnetic field of 2.2 kG for three conditions of laser light (σ_+,σ_- and no light) are shown in Fig. 6 for a deuterium flow of 2.1×10^{17} atoms/s. Clearly, from the observation of the three distinct curves shown in Fig. 6, the polarization of deuterium atoms is large: 73±3%.

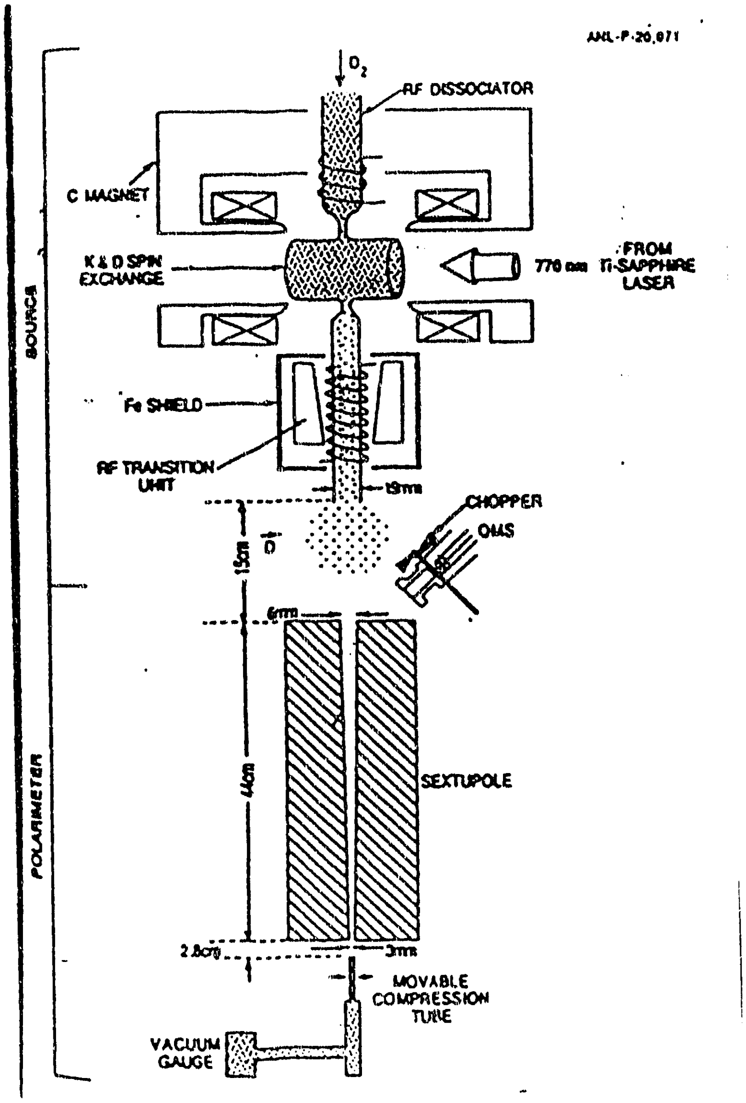

Figure 5. Schematic diagram of the high field optically-pumped spin-exchange source and the polarimeter.

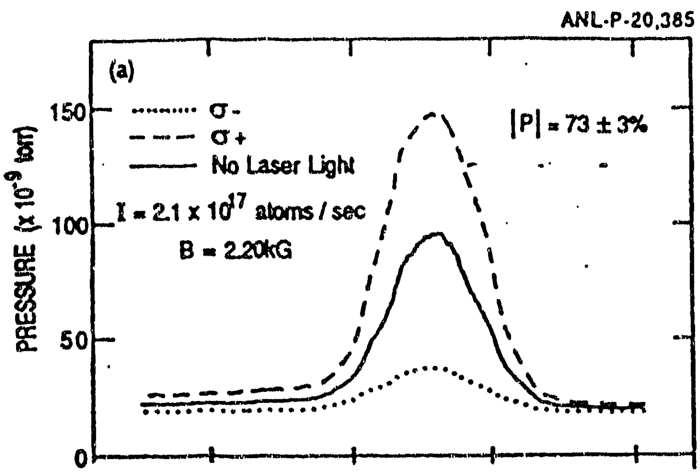

Figure 6. Signal from a scan of the compression tube and detector across the focal plane of the sextupole for three cases: (i) σ_+ light, (ii) no laser light (solid), and (iii) σ_- light (dotted curve) for a magnetic field of 2.2 kG and RF transition power off.

In order to fully demonstrate the power of the present method, we compare in Table 1 the figure-of-merit of this source with that[11] of the Novosibirsk source.

TABLE I

Source	I(/sec) (x10^{16})	P_{zz}	eff*	$F=P_{zz}^2 \times I$ (x10^{16})
Novosibirsk	1.5	0.9	0.5	0.6
ANL-91 (HF)	42	0.41=0.6x7.5x0.9	1.0	7.1

*Injection efficiency-estimate based on experience with source and storage cell at INP-Novosibirsk.

3. Photodisintegration of the Deuteron

Results[19] for the differential cross section for two-body break-up of the deuteron at high energy were obtained from SLAC experiment NE8. The experiment involved focussing electrons from the SLAC NPAS injector in the energy range 0.8 to 1.8 GeV in steps of 0.2 GeV onto a Cu bremsstrahlung radiator. The photons from this process irradiated a liquid deuterium target and the photoprotons were momentum-analyzed in the 1.6-GeV spectrometer. A time-of-flight system and dE/dx detectors were used to identify protons. An aerogel Cerenkov detector was used to check that no pions were leaking through the particle identification system.

The results from experiment NE8 at center-of-mass reaction angles of 90°, 114°, and 143° are shown as the darkened points in Fig. 7 and compared with previous data as well as a meson-exchange calculation by T.-S. H. Lee[20]. The disagreement with the meson-exchange model prompted us to consider other energy dependences, for example that expected from constituent counting rules and the reduced nuclear amplitude analysis.

A meson-exchange calculation by the Bonn group was presented at the PANIC 90 meeting and these results are shown in Fig. 8 for 90°. In this calculation, Y. Kang *et al.*[21] included all nucleon resonances with spin $\leq 5/2$. This very ambitious approach agrees better with the data as shown in the figure. One concern regarding this calculation is that the πNN cutoff was changed arbitrarily by 40% for photon energies above 700 MeV. This procedure can change the energy dependence remarkably and most likely accounts for the improved agreement with the energy dependence of the data. No present meson-exchange calculation can simultaneously explain the energy dependence of the cross section both above and below 1.0 GeV with a constant πNN cutoff.

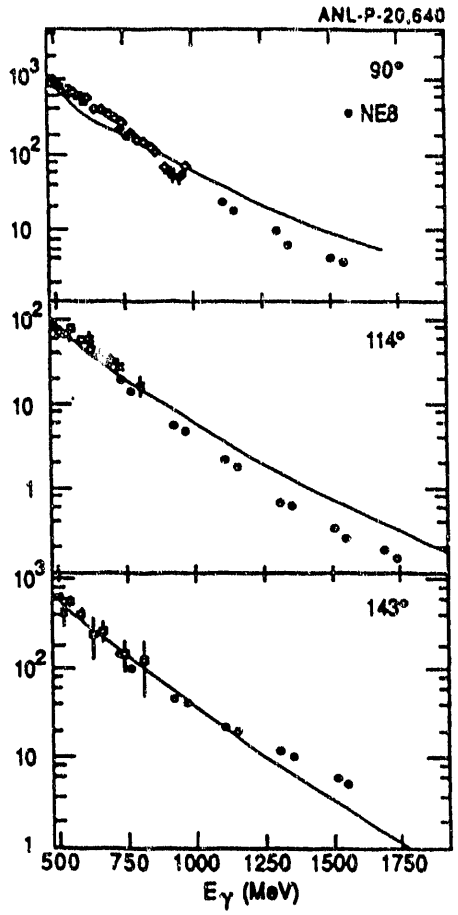

Figure 7. Cross sections from experiment NE8 at SLAC for the $\gamma d \to pn$ reaction at $\theta_{cm}=90°$, $114°$, and $143°$ are given by the solid points, the remaining data are from Ref. 20. The solid curves are predictions of T.-S. H. Lee.

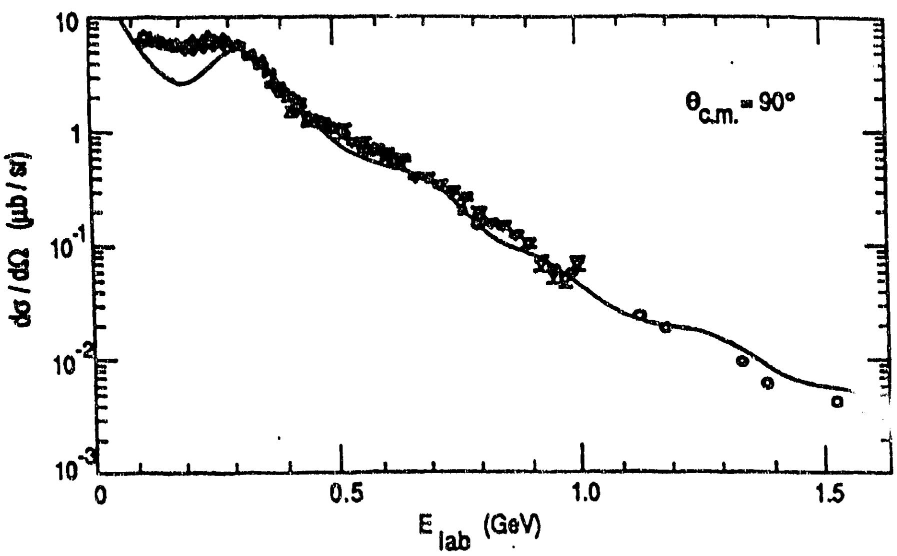

Figure 8. The cross section for the $\gamma d \to pn$ reaction at $\theta_{cm} = 90°$. The open circles are from experiment NE8 at SLAC. The solid curves represents the meson-exchange calculation of Y. Kang *et al.* and it includes nucleon resonances up to $J \lesssim 5/2$.

The application of the constituent counting rules has been very successful[23] in describing the high-momentum transfer results for electron elastic scattering from the pion and the nucleons. These results are well known and lend support to the claim that asymptotic scaling has been achieved. Although it is generally believed that the constituent counting rules can successfully describe the high momentum transfer results, there is disagreement regarding the underlying reason for their success. While S. Brodsky *et al.*[23] argue that asymptotic scaling has been observed, N. Isgur[24] contends that this apparent scaling behavior is not founded in perturbative QCD.

The constituent counting rules have met with great success in describing exclusive photoreactions for the proton at high photon energy. The most celebrated case[25] is found in the $\gamma p \rightarrow \pi^+ n$ reaction at $\theta_{cm} = 90°$. According to the constituent counting rules, the differential cross section at a fixed center of mass angle is given by

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}} \tag{6}$$

where s and t are the usual Mandelstam variables and n is the total number of constituents in the initial and final states.

It is not surprising that reactions involving only a single nucleon in the initial state can be described by quark degrees of freedom. However, for an initial state involving a nucleus it would be very surprising, since the quarks are believed to be confined to the hadrons and it would be very unlikely for all the quarks in the nucleus to be located in a very small region of the nucleus as implied by the constituent counting rules. Thus, it is very interesting to compare a photonuclear reaction to the asymptotic scaling prediction. These results for $\theta_{cm} = 90°$, 114°, and 143° are plotted as $s^{11}\ d\sigma/dt$ as a function of E_γ in Fig. 9. At the highest energies the results are consistent with the expected $1/s^{11}$ dependence.

This is a very surprising result and at first appears to be at variance with the elastic electron-deuteron scattering data.[23] After all, if we have not seen evidence for the onset of asymptotic scaling at $Q^2 = 4$ GeV^2 in e-d scattering, why do the data near a photon energy of 1.5 GeV appear to be consistent with asymptotic scaling? The main problem is how to compare the two experiments on the same scale. The important scale is the momentum transferred to the individual quarks in the two reactions. For a matter of simplicity we will consider only the momentum transferred to the nucleons in the deuteron in the two cases. In the case of e-d scattering the average momentum transfer to a nucleon in the deuteron is just $(Q/2)^2$. It turns out that the magnitude of the momentum transfer[25] to a nucleon in the deuteron in the photo-disintegration process is approximately $2m_dT_d$. For the same momentum transfer to a nucleon in e-d scattering at $Q^2 = 4$ (GeV/c)^2, the corresponding photon energy is 1.1 GeV in the photodisintegration process. Thus, the fact that the photo-

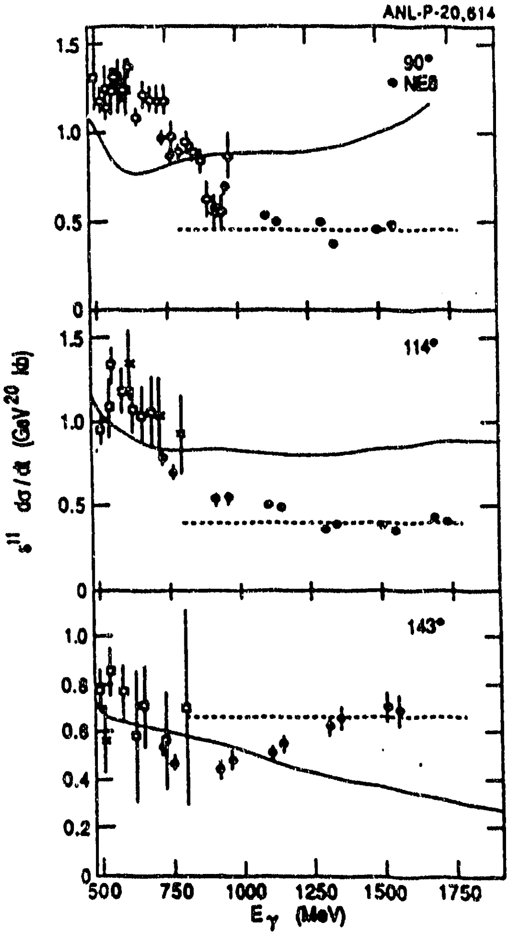

Figure 9. $s^{11}d\sigma/dt$ for the $\gamma d \to pn$ reaction at θ_{cm} = 90°, 114° and 143° as a function of photon energy. The energy dependence of the data at the highest energies is remarkably consistent with the s^{-11} dependence expected from the constituent counting rules (dotted curve). The solid curves are the meson-exchange calculations of T.-S. H. Lee.

disintegration data are consistent with asymptotic scaling above a photon energy of 1.3 GeV is not inconsistent with existing electron-deuteron scattering data.

The main problem with making a strong conclusion regarding a consistency with the constituent counting rules is that the s-range of the consistency with the rules is rather small. One of the main motivations for experiment NE17 was to extend the range of measurements to higher s. Preliminary results from experiment NE17 go up to E_γ = 2.8 GeV at θ_{cm} = 90° and appear to follow the s^{-11} dependence.

Brodsky and Chertok[26] proposed that one could better see the onset of scaling in electron scattering from nuclei if the nucleon form factors were first removed from the cross section data. This approach represents a significant departure from conventional models of electron scattering. In the conventional picture the scattering amplitude for the impulse approximation depends on the product of the nucleon form factor and the body form factor of the nucleus. However, in the reduced nuclear amplitude model the scattering amplitude depends on the product of the nucleon form factors for each nucleon in the nucleus. This factorization has been shown to be valid in the limit that the nucleons are unbound, and it is argued that binding effects are small at very high momentum and energy transfers.

Brodsky and Hiller[27] first applied the reduced nuclear amplitude analysis to two-body photodisintegration of the deuteron. At that time the highest energy data were at a photon energy of 1 GeV. The prediction for the differential cross section from this model is given by

$$\frac{d\sigma}{d\Omega} = \frac{1}{[s(s-M_d^2)]^{1/2}} F_p^2(t_p)\, F_n^2(t_n)\, f^2(\theta_{cm})\,/p_T^2 \tag{7}$$

where the F_i are the nucleon form factors, $t_i = (p_i - p_d)^2$, and p_T is the transverse momentum.

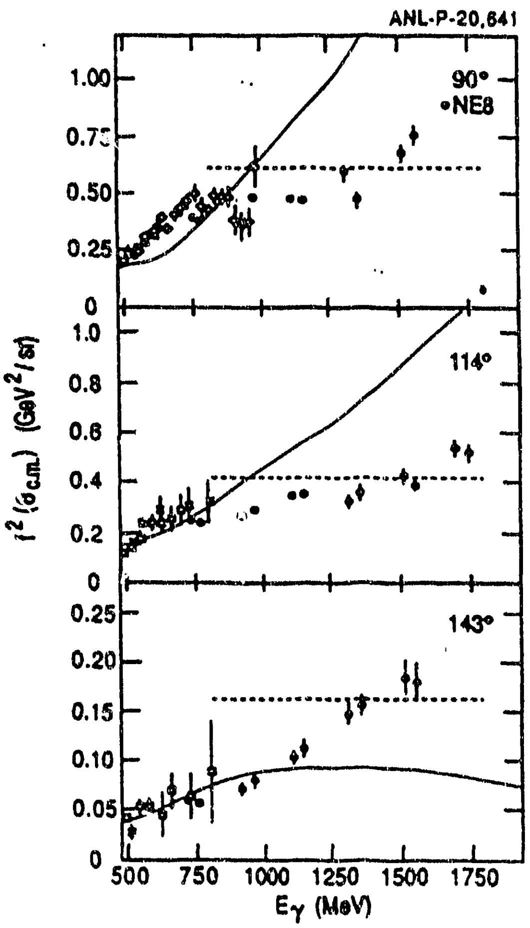

Figure 10. The reduced nuclear amplitude $f^2(\theta)$ for the $\gamma d \to pn$ reaction at angles of $\theta_{cm} = 90°$, 114° and 143° as a function of photon energy. The energy dependence appears to be in reasonable agreement with that expected by Brodsky and Hiller. The solid curves are the same calculations as those of Fig. 9.

Here $f(\theta)$ is the reduced nuclear amplitude that is expected to have no energy dependence where this model is valid. The results for $f^2(\theta)$ from experiment NE8 are given in Fig. 10. At center-of-mass angles of 90° and 114° the data do not show a strong energy dependence for $f(\theta)$ at photon energies above 1 GeV. However, the results at 143° are in worse agreement with the model. Again, it is essential to extend these measurements to higher energy as a more stringent test of the model.

A new meson-exchange calculation by Lee and Coester[28] is based on light-front dynamics. This calculation can explain some of the backward enhancement, however, an arbitrary inelasticity must be added to the final state interaction for this purpose.

3. Summary

The new T_{20} data for e-d scattering clearly constrain the nuclear models. Only a few of the numerous calculations are in reasonable agreement with $A(Q^2)$, $B(Q^2)$ and T_{20}. Further constraints will arise from better measurements of the nucleon form factors and better data for T_{20}. The quality of data for $A(Q^2)$ and $B(Q^2)$ are unprecedented in electron scattering. "Smoking gun" signatures for QCD in e-d scattering have been ruled out by the T_{20} data below 1 $(\mathrm{GeV}/c)^2$.

Presently, it appears that the energy dependence of the cross section, $d\sigma/dt$, follows the constituent counting rules at $\theta_{cm} = 90°$, but at smaller angles falls off more slowly than constituent counting. The angular distribution is very forward peaked at high energy, but there is almost no data for large angles. The complete angular distribution at high energy should be measured[29] at SLAC or CEBAF to confirm the suggestion of forward and backward enhancement of the cross section.

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REFERENCES

1. M. I. Haftel, L. Mathelitsch, and H. F. K. Zingl, *Phys. Rev.* C **22** (1980) 1285.
2. R. Arnold et al., *Phys. Rev. Lett.* **35** (1975) 776.
3. R. Cramer et al., *Z. Phys.* C **29** (1985) 513.
4. S. Platchkov et al., *Nucl. Phys.* **A510** (1990) 740.
5. S. Auffret et al., *Phys. Rev. Lett.* **54** (1985) 649; P. E. Bosted et al., *Phys. Rev.* C **42** (1990) 38.
6. P. L. Chung et al., *Phys. Rev.* C **37** (1988) 2000.
7. E. Hummell and J. A. Tjon, *Phys. Rev. Lett.* **63** (1989) 1788.
8. R. Schiavilla and D. O. Riska, *Phys. Rev.* C **43**, (1991) 437.
9. R. Gilman et al., *Phys. Rev. Lett.* **65** (1990) 1733.
10. I. The et al., *Phys. Rev. Lett.* **67** (1991) 173.
11. A. V. Evstigneev, S. G. Popov, andd D. K. Toporkov, *Nucl. Instrum. Meth. Phys. Res., Sec.* A **238** (1985) 12.
12. M. E. Schulze et al., *Phys. Rev. Lett.* **52** (1984) 597.
13. V. F. Dmitriev et al., *Phys. Lett.* **157B** (1985) 143; B. B. Wojtsekhowski et al., *Pis'ma Zh. Eksp. Teo. Fiz.* **43** (1986) 567 [*JETP Lett.* **43** (1986)733].
14. C. Carlson, *Nucl. Phys.* A508 (1990) 481c.
15. W. P. Sitarski, P. G. Blunden, and E. L. Lomon, *Phys. Rev.* C **36** (1987)2479; P. G. Blunden et al., *Phys. Rev.* C **40** (1989) 1541.
16. The electron-deuteron collaboration: S. Belostotsky, K. P. Coulter, C. W. de Jager, H. de Vries, R. Gilman, E. R. Kinney, R. S. Kowalczyk, S. I. Mishnev, J. Napolitano, V. Nelubin, D. M. Nikolenko, S. G. Popov, D. H. Potterveld, I. A. Rachek, G. Retzlaff, V. Stibunov, V. Sulimov, A. B. Temhykh, D. K. Toporkov, E. P. Tsentalovich, B. B. Wojtsekhowski, L. Young, and A. Zghiche.
17. K. P. Coulter, *Phys. Rev. Lett.* **68** (1992) 174; L. Young et al., *Nucl. Phys.* **A497** (1989) 529c; A. Zghiche, Proceedings of the Workshop on Polarized Gas Targets for Storage Rings, eds. H. G. Gaul et al., Heidelbherg, September 1991, pp. 103.
18. D. R. Swenson nd L. W. Anderson, *Nucl. Instrum. Meth.* **B29** (1988) 627; L. Young et al., *ibid* **B24/25** (1987) 963.
19. J. Napolitano et al., *Phys. Rev. Lett.*
20. T.-S. H. Lee, Proceedings of the International Conference on Medium- and High-Energy Nuclear Physics, Taipei, Taiwan, 23-27 May 1988, eds. W.-Y. Pauchy Hwang, Keh-Fei Liu, and Yiharn Tzeng, (World Scientific, Singapore, 1989) pp. 563-569.

21. J. Arends et al., *Nucl. Phys.* **A412** (1984) 509; P. Dougan et al., *Z. Phys.* **A276** (1976) 55; R. Ching and C. Schaerf, *Phys. Rev.* **141** (1966) 1320.
22. Y. Kang et al., Proceedings of the Particle and Nuclear Conference, MIT, Cambridge, MA (1990) p. I-40.
23. S. J. Brodsky, *Comments Nucl. Part. Phys.* **12** (1984) 213.
24. N. Isgur and C. H. Llewellyn Smith, *Nucl. Phys.* **B317** (1989) 526.
25. R. J. Holt, *Phys. Rev.* **C41** (1990) 2400.
26. S. J. Brodsky and B. T. Chertok, *Phys. Rev. Lett.* **37** (1976) 269.
27. S. J. Brodsky and R. J. Hiller, *Phys. Rev.* C **28** (1983) 475. Note that the phase space factor in Eq. (3.2) of this reference is incorrect. We use the corrected form as written in this Letter. Also, the relation $P_T^2 = tu/s$ used in this reference is valid only for $s >> M_N^2$. We use the correct relativistic expression, as did the authors of this reference. (J. R. Hiller, private communication.)
28. T.-S. H. Lee and F. Coester, private communication (1991).
29. R. J. Holt et al., CEBAF Proposal 89-012 (1989).

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