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ELASTIC ELECTRON-DEUTERON SCATTERING AND POSSIBLE MESON-EXCHANGE EFFECTS*

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We have obtained data on elastic electron-deuteron scattering using a two-spectrometer coincidence-detection technique. The electron beam was supplied by the Stanford Mark-III accelerator. Both the electric and magnetic scattering have been measured at values of q^2 of 6, 7, 8, and 12 F^{-2}. ($-q^2$ is the square of the four-momentum transferred.) The accuracy for electric scattering is 6 to 12%; for magnetic scattering, 12 to 20%. Electric scattering was also measured at $q^2 = 20$ F^{-2} with 25% accuracy. Our preliminary analysis of the data has been compared with an impulse-approximation theory and has enabled us to investigate possible meson-exchange and/or relativistic effects.

The measurements were made using a 1.2-cm-thick liquid-deuterium target and two 180°, $n=\frac{1}{2}$, double-focusing magnetic spectrometers. Deuterons were deflected by a 72-in., 1000-MeV/c spectrometer and detected by a six-channel ladder of plastic scintillators. Electrons were deflected by a 36-in., 550-MeV/c spectrometer and detected by a similar five-channel ladder with a liquid Cherenkov backing counter. The solid angle was defined by the 36-in. spectrometer. By demanding a coincidence between counts from each spectrometer, background events from competing inelastic processes were eliminated. Delayed accidental coincidence rates were monitored. These accidental rates were typically less than 20% of the real rate and introduced less than a 2% uncertainty in the final quoted cross sections. About a 20% radiative correction was necessary for the electron detection; less than a 1% correction was necessary for the deuteron detection.

Elastic electron-proton cross sections were also measured and used for normalization purposes, thus reducing possible systematic errors from sources such as solid angle, radiative corrections, target thicknesses, and target density. Our quoted deuteron cross sections were normalized to these proton measurements, using the b' fit of de Vries et al.[1] as an accurate standard; i.e., no error was assigned to the b' fit predictions.

The proton cross sections measured with the two-spectrometer coincidence system were compared with those measured simultaneously using only the 36-in.-spectrometer information. The efficiency of the two-spectrometer system thus obtained was typically $(98.5 \pm 1.5)\%$.

Assuming only a one-photon exchange, one can write

$$\frac{(d\sigma/d\Omega)}{\sigma_{NS}} = A(q^2) + B(q^2)\tan^2(\tfrac{1}{2}\theta),$$

where $d\sigma/d\Omega$ is the experimental cross section. σ_{NS} is the point cross section (including recoil factor), θ is the electron scattering angle in the laboratory, and $A(q^2)$ (referred to as the electric scattering) and $B(q^2)$ (referred to as the magnetic scattering) are functions of q^2 only. For each value of q^2 (except 20 F^{-2}) measurements were made at electron scattering angles of 90°, 120°, and 145°. The values of $A(q^2)$ and $B(q^2)$ were obtained by plotting $(d\sigma/d\Omega)/\sigma_{NS}$ against $\tan^2(\frac{1}{2}\theta)$ and fitting these data with a minimum χ^2 straight line. The χ^2/(de-

Table I. Experimental results.

q^2	Electron angle	$d\sigma/d\Omega$ (10^{-36} cm^2/sr) (%)	σ_{NS} (10^{-34} cm^2/sr)	$100(d\sigma/d\Omega)/\sigma_{NS}$	100 $A(q^2)$ (%)	100 $B(q^2)$ (%)
6	90°	617 ± 5.0	610	1.011 ± 0.051	0.918 ± 5.8	0.0892 ± 12.9
	120°	221 ± 6.6	188	1.176 ± 0.078		
	145°	97.3 ± 5.5	53.5	1.819 ± 0.091		
7	90°	331 ± 4.8	508	0.653 ± 0.029	0.571 ± 5.6	0.0739 ± 12.3
	120°	119 ± 6.3	155	0.765 ± 0.048		
	145°	58.7 ± 5.9	44.1	1.331 ± 0.078		
8	90°	180 ± 3.8	433	0.415 ± 0.016	0.363 ± 5.0	0.0523 ± 11.7
	120°	68.7 ± 7.1	131	0.525 ± 0.037		
	145°	33.0 ± 6.1	37.2	0.887 ± 0.054		
12	90°	29.0 ± 8.5	263	0.110 ± 0.010	0.0895 ± 11.9	0.0164 ± 19.5
	120°	9.28 ± 14.9	78.1	0.119 ± 0.018		
	145°	5.81 ± 10.5	21.9	0.266 ± 0.028		
20	90°	2.93 ± 19.0	136	0.0216 ± 0.0041	0.0171 ± 25.7	

grees of freedom) varied from 0.1 to 1.3. At $q^2 = 20$ F^{-2}, only a 90° measurement was made; to obtain the quoted value for the electric scattering, the magnetic contribution was estimated (by extrapolating our results at lower values of q^2) and subtracted.

The preliminary results are summarized in Table I and are plotted in Figs. 1 and 2.

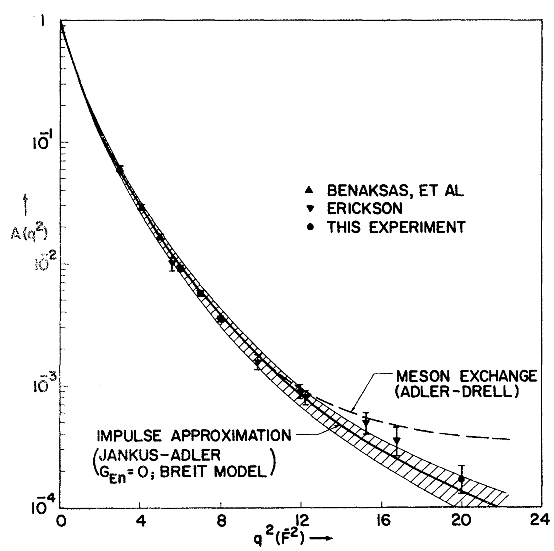

FIG. 1. Comparison of experimental values of $A(q^2)$ with predictions based on impulse-approximation theory. The solid curve is the impulse-approximation prediction with no corrections; the dashed curve is the theoretical prediction with the Adler-Drell correction (assuming constant ρ-π-γ coupling) included. The cross-hatched area indicates the uncertainties in the uncorrected predictions from sources as G_{ES} and deuteron wave functions (see text).

We estimate that our final analysis of these data will change the cross sections quoted here by less than 2%. Figures 1 and 2 also include measurements of $A(q^2)$ and $B(q^2)$ reported by Benaksas, Drickey, and Frerejacque,[2] and of $A(q^2)$ by Erickson.[3] We have normalized the absolute deuteron cross sections reported by Benaksas, Drickey, and Frerejacque using their quoted proton cross sections and the b' fit of de Vries et al.

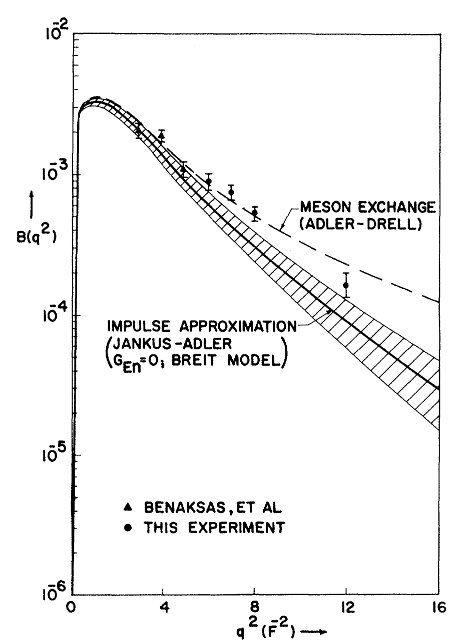

FIG. 2. $B(q^2)$ compared with impulse-approximation-theory predictions, with and without the Adler-Drell correction. See caption for Fig. 1.

We have assumed the following impulse approximation formulation[4]:

$$A(q^2)=(1-\eta)^2[G_C{}^2(q^2)+G_Q{}^2(q^2)]+\frac{8}{3}\eta G_M{}^2(q^2),$$

$$B(q^2)=\frac{16}{3}\eta(1+\eta)G_M{}^2(q^2),$$

where

$$G_C=G_{ES}I_C,$$

$$G_Q=G_{ES}I_Q,$$

$$G_M=G_{MS}I_{M1}+G_{ES}I_{M2},$$

$$\eta=q^2/4M_D{}^2.$$

G_C, G_Q, and G_m are form factors associated with the deuteron's charge, electric quadrupole moment, and magnetic dipole moment, respectively. G_{ES} and G_{MS} are the isoscalar electric and magnetic nucleon form factors. I_C, I_Q, I_{M1}, and I_{M2} are well-known integrals over the deuteron wave functions.[5] The predictions of this theory are shown by the solid curves in Figs. 1 and 2. The cross-hatched regions indicate the range of uncertainties in the predictions caused by uncertainties in the quantities entering into the theory.

Adler and Drell[6] have estimated the corrections to electric and magnetic scattering caused by including the most important allowed meson-exchange diagram: namely, the diagram involving a ρ-π-γ vertex. Their calculated correction to the static-magnetic dipole moment is large enough (but of undetermined sign) to explain the difference between the experimentally observed value and the value predicted assuming a 7% D state. The dashed curves in Figs. 1 and 2 include the results of Erickson's[4] numerical analysis of the Adler-Drell calculation: Namely, the ρ-π-γ meson-exchange correction is assumed to be of the proper size and sign to explain the discrepancy in the static moment, the couplings (including the ρ-π-γ coupling) assumed to be constant.

In obtaining numerical predictions from the theory, we have used wave functions determined by the Yale model of the deuteron.[7] For G_{ES}, we have assumed $G_{EN}=0$ and have obtained values of G_{EP} from the b' fit of de Vries et al. Because G_{MS} is quite sensitive to uncertainties in G_{MP} and G_{MN}, we have obtained values for G_{MS} by visually fitting the data of Hand, Miller, and Wilson[8] and the data of Janssens et al.[9] for G_{MP}, and the data of Hughes et al.[10] for G_{MN}. One alternatively could obtain values of G_{MS} by assuming the b' fit [giving values of $B(q^2)$ in the lower part of the cross-hatched region] or by assuming "scaling" of the nucleon form factors [giving values of $B(q^2)$ near the upper edge of the cross-hatched region]. Our analysis of the data of Hand, Miller, and Wilson, of Janssens et al., and of Hughes et al. indicates that both these alternate assumptions are less probable, but at present neither can be conclusively excluded.

Both the uncertainties in G_{ES} (estimated from data on G_{EP} and G_{EN}) and the deuteron wave functions (estimated by comparing various models used by Glendenning and Kramer[11]) contribute significantly to the uncertainty in $A(q^2)$. The uncertainties in G_{MS} (estimated by fitting data on G_{MP} and G_{MN}) dominate the uncertainties in $B(q^2)$. Both $A(q^2)$ and $B(q^2)$ contain smaller uncertainties, roughly estimated to be of the order of $(1+4\eta)$, from uncertainties in those relativistic corrections which have been calculated. Except at low values of q^2 (perhaps $\lesssim 8$ F^{-2}), there may be additional large, as yet uncalculated, relativistic corrections.

Our conclusions are as follows:

(1) Simple impulse-approximation theory, without corrections, appears not to be adequate to explain the large observed magnetic scattering. This is especially clear for our data above q^2 of 6 F^{-2}.

(2) For $q^2<10$ F^{-2}, magnetic scattering appears to agree quite well with the theory if one includes the Adler-Drell meson-exchange correction.

(3) Electric scattering, for $q^2<10$ F^{-2} (where the Adler-Drell correction is small), has been measured with high accuracy and agrees quite well with the uncorrected impulse-approximation theory.

(4) For $q^2>10$ F^{-2}, it appears probable, but not conclusive, that both $A(q^2)$ and $B(q^2)$ are larger than predicted by impulse-approximation theory without the Adler-Drell correction and smaller than predicted with it. However, if one makes the assumption that the coupling at the ρ-π-γ vertex is not constant, but rather has a form factor with a q^2 dependence of $1/(1+q^2/M_\omega{}^2)$ (where $M_\omega=4$ F^{-1} is the mass of the ω meson), then one finds that the predictions including this modified Adler-Drell correction agree rather well with all the experi-

mental data, both electric and magnetic. This, of course, is highly speculative.

(5) Thus the ρ-π-γ meson-exchange effect appears to be a good candidate for explaining the consistently large magnetic scattering observed at all values of q^2 and the possible enhancement of the electric scattering for $q^2 > 10$ F^{-2}.

We intend to extend our experimental program with further data at q^2 of 16 F^{-2} and possibly 10 F^{-2}.

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TEST FOR PARTICLE-MIXTURE THEORIES OF $K^0 \to 2\pi$ DECAY

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Christenson, Cronin, Fitch, and Turlay[1] have discovered that, in addition to the well-known short-lived 2π mode characterized by the lifetime[2] $\gamma_1^{-1} = (0.92 \pm 0.02) \times 10^{-10}$ sec, there is another $\pi^+\pi^-$-decay mode of neutral K mesons which persists at times of the order of 300 γ_1^{-1}. The lifetime associated with this second mode has not been measured accurately, but the observations are compatible with what would be expected from a $\pi^+\pi^-$- decay channel of the long-lived mode of K^0 decay [$\gamma_2^{-1} = (5.62 \pm 0.68) \times 10^{-8}$ sec] with a branching ratio of $R = (2.0 \pm 0.4) \times 10^{-3}$ with respect to all charged modes. CP invariance would require R to be strictly zero. This observation of long-lived $\pi^+\pi^-$ decays, which we shall refer to as the LLD effect, has subsequently been confirmed by two other groups[3] who find, under considerably different conditions, values of R which are substantially the same as the one previously reported. However, since there is nothing in the observations which is manifestly noninvariant under CP, and there is no clear indication of CP violation anywhere else, it is important to consider possible explanations of the LLD effect within the framework of CP invariance. In this note we describe a simple test for a class of such theories (particle-mixture theories), which represent the only proposals advanced so far which maintain CP invariance without calling upon cosmological effects.[4]

It is a common feature of all such particle-mixture theories[5-8] that they require the existence of an additional spinless particle state, which we shall denote by $|S\rangle$, with $CP = +1$, in the neighborhood of the K^0-meson mass. This