Measurement of the Tensor Polarization in Electron-Deuteron Elastic Scattering

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This paper reports the first measurement of the tensor polarization t_{20} in e-d elastic scattering. The polarization of the recoil deuterons was measured for two values of momentum transfer, $q = 1.74$ and $2.03\ \mathrm{fm}^{-1}$, with a high-efficiency polarimeter. The results are in good agreement with reasonable models for the deuteron.

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A complete experimental determination[1,2] of the electromagnetic current of the deuteron requires the measurement of at least one polarization observable, in addition to the differential cross section. Here we report the first measurement of t_{20} in elastic e-d scattering. Measurements of t_{20} have previously not been feasible because of the absence of high-efficiency deuteron tensor polarimeters or tensor-polarized targets, and the lack of high-intensity electron beams and large-acceptance magnetic spectrometers. The results are found to be in good agreement with the predictions of t_{20} for "reasonable" models of the deuteron, but in disagreement with those of separable-potential models.

Electron elastic scattering from the deuteron can be described by three form factors: charge (F_C), quadrupole (F_Q), and magnetic (F_M). Thus far, only F_M has been isolated[3] in measurements of the cross section. The form factors F_C and F_Q have not been isolated previously from measurements of the structure function.[4] A determination of these form factors separately would discriminate further among different deuteron wave functions. The sensitivity of t_{20} to the deuteron wave function arises from the fact that the leading term in t_{20} is proportional to the ratio of F_Q to F_C. In this ratio, the poorly known isoscalar electric nucleon form factor drops out. The expression for t_{20} is given[2] by

$$t_{20} = -\sqrt{2}\,[X(X+2) + Y/2]/[1 + 2(X^2 + Y)],$$

where $X = \frac{2}{3}\eta F_Q/F_C$, $Y = \frac{2}{3}\eta f(\theta) F_M{}^2/F_C{}^2$, $\eta = q^2/4M_d{}^2$, and $f(\theta) = \frac{1}{2} + (1+\eta)\tan^2(\theta/2)$. Here, q is the four-momentum transfer, M_d is the rest mass of the deuteron, and θ is the angle of the scattered electron. The terms involving powers of X in the numerator are dominant in the momentum transfer region of $1-5\ \mathrm{fm}^{-1}$. Thus, t_{20} is sensitive to the ratio of F_Q to F_C. The quantity F_Q is sensitive to the tensor part of the N-N interaction, while F_C is dominated by the S-wave part of the deuteron wave function at these values of low momentum transfer. Additionally, recent work[1,2] has shown that t_{20} is also sensitive to the isoscalar meson exchange current (MEC) and relativistic corrections, about which there is much controversy.[5]

The experiment was performed at the South Experimental Hall of the Massachusetts Institute of Technology–Bates Linear Accelerator Center. A schematic diagram of the experimental arrangement is given in Fig. 1. The electrons from the linac were focused on a windowless D_2O target which consisted of a 0.38- or 0.64-mm-thick laminar flow of heavy water. The incident electron energies were 371 ± 2 MeV for $q = 2.03\ \mathrm{fm}^{-1}$, and 310 ± 1.8 MeV for $q = 1.74\ \mathrm{fm}^{-1}$. During the experiment the average current and duty factor of the electron beam varied from 15 to 50 μA and 0.3% to 0.4%, respectively. The scattered electrons were detected in the "one-hundred-inch proton spectrometer" (OHIPS)[6] while the recoil deuterons were selected with the "big-bite" spectrometer[7] and focused onto the polarimeter. The acceptance of "big bite" was 15 msr with a dispersion of 1.7 cm/%, and the OHIPS acceptance was 20 msr with 4.5 cm/% dispersion. A wedge-shaped degrader fabricated from strips of Al foil was located before the polarimeter in order to

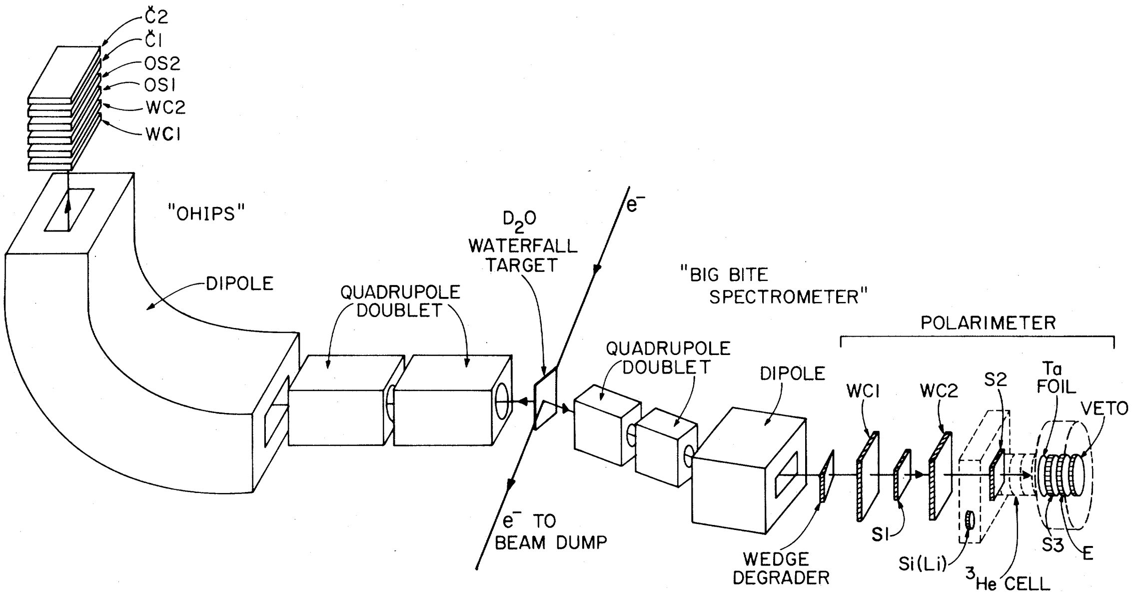

FIG. 1. Schematic diagram of the experimental arrangement.

reduce the spread in deuteron energies incident upon the polarimeter. In addition, graphite absorbers were used at the higher energy to slow the deuterons to the operating energy range (18–27 MeV) of the polarimeter. The energy spread (full width at half maximum) of the deuterons at the polarimeter was 2.1 MeV at $q = 1.74$ fm^{-1} and 3.6 MeV at 2.03 fm^{-1}.

The polarimeter was previously used for the measurement of t_{20} in π-d elastic scattering at the Clinton P. Anderson Meson Physics Facility (LAMPF). Since a description of this polarimeter has been presented by Holt *et al.*[8] and a simpler prototype was discussed in detail by Stephenson *et al.*,[9] only a brief description of the polarimeter will be given here. The polarimeter makes use of the reaction ^{3}He$(d,p)^4$He which is known to have a large cross section and analyzing power for t_{20} at forward reaction angles. In addition, the Q value for this reaction is large (18.4 MeV) which allows for identification of protons from even a relatively thick (~100 mg/cm^2) ^{3}He target. Deuterons were identified by observing their energy loss in two 0.8-mm-thick plastic scintillators (S1 and S2 in Fig. 1) which preceded the ^{3}He volume, while the time of flight of the particles between S2 and E was used to identify reaction protons. This time-of-flight interval consisted of the slowing-down time of the deuteron in the ^{3}He and the ensuing flight time of the reaction proton. In addition, the dE/dx and total energy signals of the protons were measured with the S3 and E detectors to provide additional discrimination against background. A veto detector was located at the end of the polarimeter in order to eliminate protons of higher energy than the reaction protons. The major source of background was random coincidences between electrons and protons or deuterons from photodisintegration of oxygen and deuterium in the target. After application of the software filters, these random events contributed about 1.5% to the detected deuterons and about 10% of the detected (d,p) events. The trajectory of each deuteron entering the polarimeter was determined by two wire chambers (WC1 and WC2). In addition, the energy spectrum of deuterons was determined with a 2.0-cm-diam by 5-mm-thick Si(Li) detector which was used periodically to map the energy distribution of the deuteron beam as a function of position at the entrance to the polarimeter in order to determine the efficiency and analyzing power from the calibration. The efficiency and analyzing power of the polarimeter were calibrated in separate measurements using deuteron beams available at the Berkeley 88-in. cyclotron and at the tandem Van de Graaff at Los Alamos National Laboratory.

The dipole magnet of the big-bite spectrometer was used to analyze the scattered deuterons by deflecting them through 45°. This bending introduced a precession (φ) of the deuteron's spin of $-6.52°$ at $q = 1.74$ fm^{-1} and $-6.56°$ at 2.03 fm^{-1}.

TABLE I. Measured values of t_{20}^p and corresponding values for t_{20}.

q (fm^{-1})	t_{20}^p measured	t_{20} extracted	t_{20} (Paris) calculated TOT	IA
1.74	$-0.42\pm0.06(\pm0.04)$	$-0.41\pm0.06(\pm0.04)$	-0.446	-0.419
2.03	$-0.59\pm0.13(\pm0.06)$	$-0.58\pm0.13(\pm0.06)$	-0.614	-0.573

After precession, the tensor polarization measured in the polarimeter, t_{20}^p, is related to the tensor polarizations, t_{ij}, involved in e-d elastic scattering by

$$t_{20}^p = [\tfrac{3}{2}\cos^2(\varphi)-\tfrac{1}{2}]t_{20}-(\tfrac{3}{2})^{1/2}\sin(2\varphi)t_{21} + (\tfrac{3}{2})^{1/2}\sin^2(\varphi)t_{22}.$$

In order to extract t_{20}, the values of t_{21} and t_{22} were taken from a calculation with the Paris[10] wave functions for the deuteron. The effect of this spin precession is small, as shown in Table I. The model dependence of this correction is negligible when compared with other uncertainties. Values of t_{20} are given in Table I. The total errors given in the table combine statistical with systematic uncertainties in quadrature. The values in parentheses indicate only the systematic errors in the measurements. These systematic errors are due primarily to the uncertainty in the energy of the deuterons at the polarimeter entrance and calibration of the analyzing power of the polarimeter to that of d-α elastic scattering.

Our extracted values of t_{20} are compared with theoretical predictions of the Paris,[10] Feshbach-Lomon (FL4.6),[11] and Graz[12] potential models in Table I and Fig. 2. These predictions are given for the impulse approximation (IA) and also for inclusion of relativistic[13] and MEC corrections[14] (TOT). It is clear that the Paris and FL4.6 models are in excellent agreement with the data. Other "reasonable" potential models yield similar results[1,2] in agreement with these data and other elastic e-d data at low momentum transfer. In Table I we show numerical predictions for t_{20} of the Paris potential.

In this region of low momentum transfer, t_{20}, the quadrupole moment Q, and the asymptotic D-wave amplitude A_D are determined mainly by the long-range part of the N-N force (one-pion-exchange potential) and are intimately related to each other as well as to the size of the deuteron D state. Not all "reasonable" potentials have been constrained to yield the measured values of Q and A_D. As shown by Hadjimichael,[15] variations in model predictions for Q persist when corrections are made for known MEC and relativistic effects. However, if one assumes the existence of additional MEC corrections having the same dependence on q as those of Gari and Hyuga[14] and being the correct size to bring all reasonable models into agreement with Q, the model dependence of predictions for t_{20} becomes even smaller.[16] All calculations then give results essentially identical to those shown for FL4.6 in Fig. 2 for $q^2 \lesssim 8$ fm^{-2}. Significant differences between these "scaled" predictions do appear at higher values of q and are of the same order as the differences between the Paris and FL4.6 predictions.

The present results are not of sufficient accuracy to confirm the presence of MEC effects. In order to provide more stringent constraints on the deuteron wave function and the effects of iso-

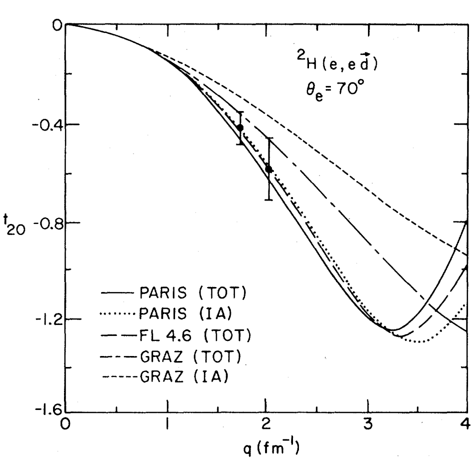

FIG. 2. The two data points indicate the present results. The curves represent predictions of different potential models: Paris, TOT (solid curve); Paris, IA (dotted curve); FL4.6, TOT (long-dashed curve); Graz, TOT (long-short–dashed curve); Graz, IA (short-dashed curve).

scalar MEC's, measurements of this kind should be performed with higher accuracy and at higher momentum transfer.

In conclusion, we have performed the first measurements of t_{20} in elastic electron-deuteron scattering. The results agree with predictions of reasonable models of the deuteron.

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