Out-of-Plane Measurement of the D(e, e'p) Coincidence Section

著者	Tamae T., Kawahara H., Tanaka A., Nomura M., Namai K., Sugawara M., Kawazoe Y., Tsubota H., Miyase H.
journal or publication title	Physical Review Letters
volume	59
number	26
page range	2919-2922
year	1987
URL	http://hdl.handle.net/10097/53260

doi: 10.1103/PhysRevLett.59.2919

Out-of-Plane Measurement of the D(e,e′p) Coincidence Cross Section

T. Tamae, H. Kawahara, A. Tanaka, M. Nomura, K. Namai, and M. Sugawara
Laboratory of Nuclear Science, Tohoku University, Mikamine, Sendai 982, Japan

Y. Kawazoe
Education Center for Information Processing, Tohoku University, Kawauchi, Sendai 980, Japan

and

H. Tsubota and H. Miyase
College of General Education, Tohoku University, Kawauchi, Sendai 980, Japan
(Received 5 October 1987)

The D(e,e′p) coincidence cross section was measured at angles out of the plane, at an excitation energy of approximately 18 MeV and a momentum transfer of 0.33 fm^{-1}. This is the first reported measurement of the longitudinal-transverse and transverse-transverse interference terms of the electrodisintegration cross section of the deuteron. The longitudinal plus transverse cross section is also reported. The results are in good agreement with a theoretical calculation carried out with use of the Paris potential.

PACS numbers: 25.30.Fj, 25.10.+s, 27.10.+h

With the advent of high–duty-cycle electron accelerators, new types of experiments, such as coincidence experiments[1,2] and polarization experiments,[3,4] have become possible. These experiments have the potential to become very powerful tools for probing nuclear structure and the nuclear force.

The deuteron, as a two-nucleon system, is of great importance in the investigation of the N-N interaction, and thus providing a surer foundation for the study of heavier nuclei. Of special interest in the case of the deuteron is the study of interaction effects such as mesonic-exchange currents (MEC's) and the influence of nuclear isobar configurations (IC's).[5,6] Relativistic effects are also of interest in the reaction.[7] Although the importance of an out-of-plane measurement in D(e,e′p) coincidence experiments was mentioned some time ago,[6] no experiments have actually been made, because such experiments are difficult to perform with pulsed electron accelerators. The pulse stretcher[8] constructed at Tohoku University made it possible to perform such coincidence experiments. The out-of-plane coincidence experiment for the D(e,e′p) reaction is one of the first such experiments using the high-duty electron beam.

In the (e,e′p) coincidence experiment, the direction of the emitted proton momentum **p** is determined by two angles: θ_p, the polar angle between **p** and the momentum transfer **q**, and ϕ, the azimuthal angle between the scattering plane and the reaction plane. The situation is shown in Fig. 1. The coincidence cross section in the laboratory frame is given by

$$d^3\sigma/d\omega\, d\Omega_e d\Omega_p = (d^3/d\omega\, d\Omega_e d\Omega_p)(\sigma_L + \sigma_T + \sigma_{LT}\cos\phi + \sigma_{TT}\cos 2\phi). \quad (1)$$

The expression for the cross section includes two interference terms involving the longitudinal-transverse (σ_{LT}) and the transverse-transverse (σ_{TT}) cross sections in addition to the longitudinal (σ_L) and transverse (σ_T) components. These interference terms are not present in inclusive electron-scattering experiments, where no outgoing nucleons are detected. The interference terms are expected to give new information about the N-N interaction. The transverse-transverse term, in particular, is sensitive to the existence of MEC's and IC's. According to Eq. (1), an out-of-plane measurement of the coincidence cross section enables the interference terms to be separated from other components.

We measured the D(e,e′p) coincidence cross section in reaction planes at $\phi = 45°$, 90°, and 135°, and at excitation energies of approximately 18 MeV. A deuterat-

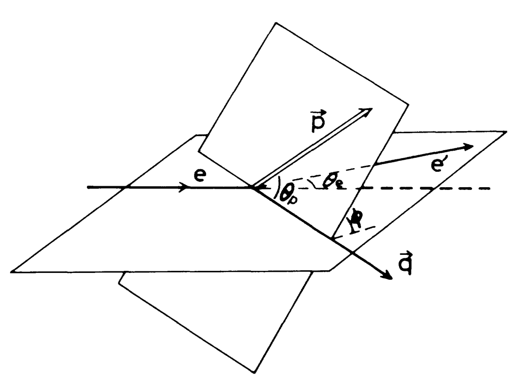

FIG. 1. Geometry of the coincidence D(e,e′p) experiment in the laboratory frame.

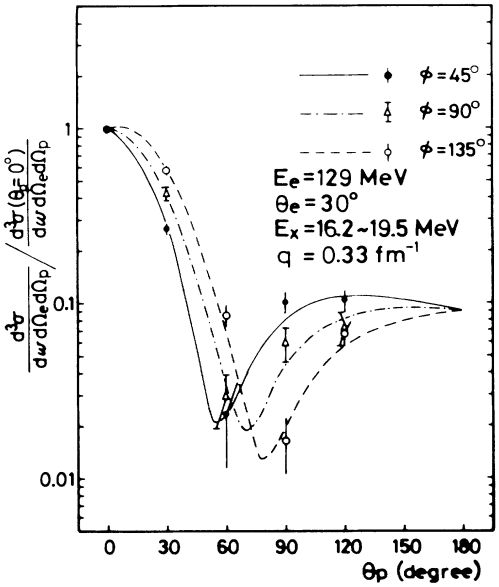

FIG. 2. Angular dependence of the D$(e,e'p)$ cross section for $\phi=45°$, 90°, and 135°. Curves: calculation with the Paris potential by Arenhövel (Ref. 9).

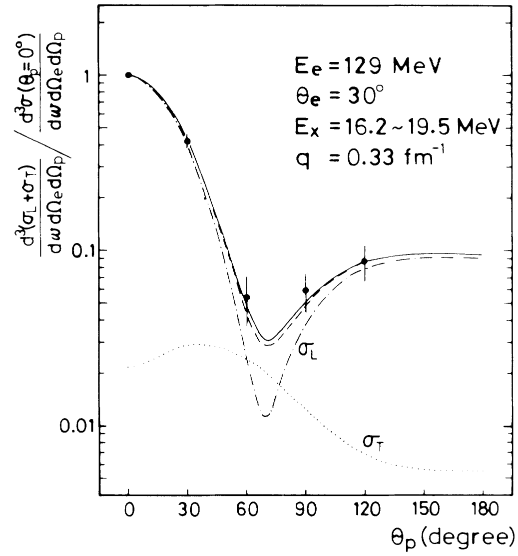

FIG. 3. Angular dependence of the sum of the longitudinal and transverse cross sections for D$(e,e'p)$. The solid curve shows the result of a calculation which includes MEC's and IC's (Ref. 9). The dash-dotted line shows the longitudinal component, and the dotted line the transverse component in the same calculation. The dashed curve is the sum of these component cross sections calculated without MEC's and IC's.

ed polyethylene $(C_2D_4)_n$ foil of thickness 20 mg/cm^2 was irradiated by a continuous beam of 129-MeV electrons. The scattered electrons were measured at 30° in a double-focusing magnetic spectrometer with a solid angle of 6 msr and an energy acceptance of 5%. An array of three multiwire proportional chambers and two 5-mm-thick plastic scintillators was used in the focal plane. Protons were detected with 1-mm-thick surface-barrier solid-state detectors (SSD's) set around the target inside the vacuum chamber. These were placed at polar-angle intervals of 30° in each reaction plane. The distance between the detectors and the target was approximately 13 cm. The active area of each SSD was around 260 mm^2. The solid angle of each proton detector was measured experimentally with α particles from a ^{231}Am source placed at the target position. It was determined from the number of α particles seen by each detector compared to the number seen by a standardized detector with a 100-mm^2 collimator in front of it, which was placed a known distance from the source. The pulse-height to energy-loss ratio of each SSD was determined with the same α source.

The time correlation between scattered electrons detected by the scintillators and the protons detected by the SSD's was obtained with use of time-to-digital converters. A sharp peak with a FWHM of approximately 7 nsec was observed on the continuum background in each time-correlation spectrum. The event ratio of true to accidental coincidences ranged from $\frac{1}{3}$ (at $\phi=45°, \theta_p=60°$) to $\frac{80}{1}$ (at $\theta_p=0°$). Each spectrum was used to correct for the background of accidental coincidences. For each coincidence event, the following information was stored in an on-line computer through a CAMAC system: the fired channel number of the multiwire proportional chambers, the pulse height of the SSD signal, and the time-to-digital converter information. The event selection logic allowed simultaneous data taking for the (e,e') and $(e,e'p)$ processes.

The excitation energy (E_x) of each coincidence event was deduced from the momentum of the scattered electron; the proton energy (E_p) was determined from the pulse height from the calibrated SSD's. A two-dimensional plot of E_p and E_x was made to separate protons emitted from the deuteron and those emitted from the carbon. This separation was good for excitation energies below 20 MeV, except at extreme backward angles $(\theta_p \gtrsim 150°)$. The cross sections obtained over several

TABLE I. Measured D(e,e',p) coincidence cross section normalized to that at $\theta_p=0°$.

ϕ / θ_p	45°	90°	135°
0°		1.000 ± 0.049	
30°	0.266 ± 0.019	0.424 ± 0.039	0.576 ± 0.037
60°	0.024 ± 0.012	0.029 ± 0.010	0.085 ± 0.012
90°	0.101 ± 0.014	0.059 ± 0.013	0.016 ± 0.006
120°	0.104 ± 0.015	0.073 ± 0.016	0.067 ± 0.013

TABLE II. Deduced longitudinal plus transverse, longitudinal-transverse, and transverse-transverse cross sections,

$$\frac{d^3\sigma_X/d\omega\, d\Omega_e\, d\Omega_p}{d^3\sigma_X(\theta=0)/d\omega\, d\Omega_e\, d\Omega_p},$$

normalized to that at $\theta_p=0°$.

σ_X / θ_p	$\sigma_L+\sigma_T$	σ_{LT}	σ_{TT}
0°	1.000 ± 0.049	0	0
30°	0.421 ± 0.042	-0.219 ± 0.029	-0.003 ± 0.044
60°	0.054 ± 0.017	-0.044 ± 0.012	0.025 ± 0.017
90°	0.059 ± 0.015	0.060 ± 0.011	-0.001 ± 0.015
120°	0.086 ± 0.020	0.026 ± 0.014	0.013 ± 0.018

runs were calibrated with the (e,e') counts, because the target had partly melted from heating by the electron beam.

The measured values of the cross section are shown in Fig. 2 and Table I. They are normalized to unity at $\theta_p=0°$. The error shown includes the statistical error plus contributions due to the subtraction of the accidental coincidence events and the uncertainty in the measurement of the solid angle of the SSD's. Theoretical values calculated by Arenhövel[9] are also shown in the figure. In this calculation, the Paris potential was used and the effects of MEC's and IC's were included. The agreement between the experimental data and the calculated results is well within the experimental uncertainty.

According to Eq. (1), the average of the cross sections at $\phi=45°$ and 135° gives the sum of the longitudinal and transverse cross sections as

$$\frac{d^3(\sigma_L+\sigma_T)}{d\omega\, d\Omega_e d\Omega_p}=\frac{1}{2}\left[\frac{d^3\sigma(\phi=45°)}{d\omega\, d\Omega_e d\Omega_p}+\frac{d^3\sigma(\phi=135°)}{d\omega\, d\Omega_e d\Omega_p}\right].$$

The values deduced from the experimental results in Table I are shown in Fig. 3 and Table II. The curves in the figure are again the theoretical calculations by Arenhövel.[9] The dash-dotted curve represents the longitudinal cross section, the dotted curve the transverse one, and the solid line the sum. The calculations include the effects of MEC's and IC's. The contribution of the transverse part is relatively large around $\theta_p=70°$, because the longitudinal part is at a minimum there. The dashed line represents the calculated sum of the longitudinal and transverse cross sections without MEC's and IC's. Since the influence of these interactions is more significant on the transverse cross section, the solid and dashed curves differ around $\theta_p=70°$. Although the experimental data are in rather good agreement with the calculation which includes MEC's and IC's, they cannot definitely confirm the influence of the effects. Thus more accurate measurements are needed in order to more exactly quantify these effects.

The longitudinal-transverse (σ_{LT}) and transverse-transverse (σ_{TT}) cross sections are deduced from

$$\frac{d^3\sigma_{LT}}{d\omega\, d\Omega_e d\Omega_p}=\frac{1}{\sqrt{2}}\left[\frac{d^3\sigma(\phi=45°)}{d\omega\, d\Omega_e d\Omega_p}-\frac{d^3\sigma(\phi=135°)}{d\omega\, d\Omega_e d\Omega_p}\right],$$

$$\frac{d^3\sigma_{TT}}{d\omega\, d\Omega_e d\Omega_p}=\frac{1}{2}\left[\frac{d^3\sigma(\phi=45°)}{d\omega\, d\Omega_e d\Omega_p}+\frac{d^3\sigma(\phi=135°)}{d\omega\, d\Omega_e d\Omega_p}\right]-\frac{d^3\sigma(\phi=90°)}{d\omega\, d\Omega_e d\Omega_p}.$$

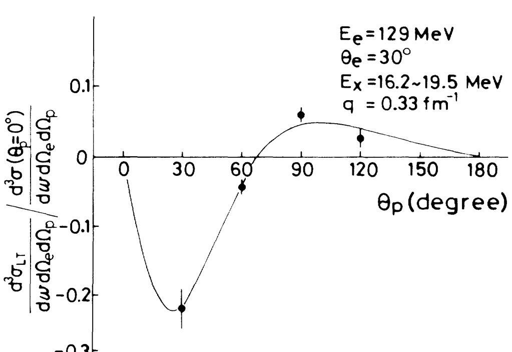

FIG. 4. Angular dependence of the longitudinal-transverse cross section for D$(e,e'p)$. Curve: calculation with the Paris potential (Ref. 9).

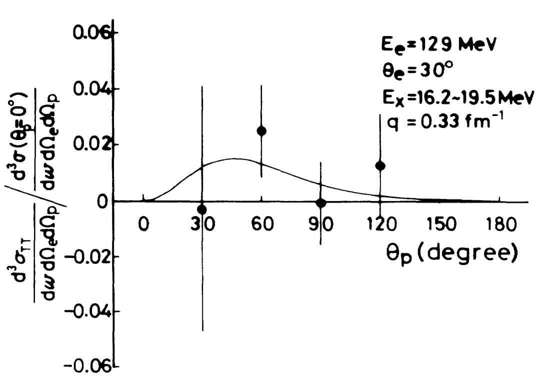

FIG. 5. Angular dependence of the transverse-transverse cross section for D$(e,e'p)$. Curve: calculation with the Paris potential (Ref. 9).

The results are shown in Figs. 4 and 5, and Table II. The interference terms vanish at $\theta_p = 0°$, as a consequence of helicity conservation. The longitudinal component changes sign at about $\theta_p = 70°$, and its absolute value is approximately half that of $\sigma_L + \sigma_T$ at $\theta_p = 30°$. The measured value of σ_{LT} is reasonably described by the theoretical prediction,[9] as shown in Fig. 4.

The value of σ_{TT} is smaller than that of σ_{LT} by 1 order of magnitude. The theory predicts its sign correctly and its magnitude is similar to the measured value. However, the measured cross section has a large error since its derivation required the subtraction of large numbers.

The effect of MEC's and IC's on the calculation of the interference terms is not large in the present energy and momentum-transfer region. The effect on σ_{LT} is a few percent, and on σ_{TT} about 15%. These effects are too small to be confirmed by the present data.

The results near 20 MeV presented here are in good agreement with the calculations. However, it is also important to make comparisons at other energies where theoretical predictions are available. Thus further experiments are in progress in a higher-energy region ($E_x = 40$ MeV), and in the region near the threshold, where the effects of MEC's and IC's become much larger. Relativistic effects, which are not included in Arenhövel's calculation, are found to be not very large[10] at $E_x = 40–60$ MeV under our experimental conditions. It may be that relativistic effects are important under certain conditions; however, there are few theoretical calculations which include relativistic effects on $(e,e'p)$ coincidence experiments. More experimental and theoretical studies of $(e,e'p)$ reactions over a large range of energy and momentum-transfer values need to be undertaken.

The authors are grateful to Professor H. Arenhövel and Professor B. Mosconi for providing calculations specific to the kinematic conditions of the present experiment. The authors also wish to thank the accelerator group and the computer group for their assistance during the experiments. The careful reading of the original manuscript by Professor M. N. Thompson is greatly appreciated. This work was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture, Japan.

[1]C. N. Papanicolas *et al.*, Phys. Rev. Lett. **54**, 26 (1985).

[2]Th. Kihm *et al.*, Phys. Rev. Lett. **56**, 2789 (1986).

[3]M. E. Schulze *et al.*, Phys. Rev. Lett. **52**, 597 (1984).

[4]M. V. Mostovoy *et al.*, Phys. Lett. B **188**, 181 (1987).

[5]S. Auffret *et al.*, Phys. Rev. Lett. **55**, 1362 (1985); W. Fabian and H. Arenhövel, Nucl. Phys. **A258**, 461 (1976), and their references.

[6]W. Fabian and H. Arenhövel, Nucl. Phys. **A314**, 253 (1979).

[7]A. Cambi, B. Mosconi, and P. Ricci, Phys. Rev. Lett. **48**, 462 (1982).

[8]T. Tamae *et al.*, IEEE Trans Nucl. Sci. **30**, 3235 (1983).

[9]H. Arenhövel, private communication.

[10]B. Mosconi, private communication.