tual exchanged object coupled to two pions.

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Observation of Meson-Exchange Effects in Deuteron Electrodisintegration

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Electrodisintegration of the deuteron has been measured for an incident energy of 300 MeV at 30° and 90° scattering angles. The maximum energy transfer was 116 MeV. Very good agreement with theory was achieved when the pionic-exchange currents were included. Near the threshold and for momentum transfer $\vec{q}_{\text{c.m.}}^{\,2} = 3.9\ \text{fm}^{-2}$, the meson-exchange currents contribute about 40% to the total cross section.

The study of the interaction effects on electromagnetic processes in nuclei, i.e., the meson-exchange currents (MEC)[1] and nucleon off-mass-shell effects in the form of nuclear isobar configurations (IC),[2] has received considerable interest in the past years. Particular attention has been paid to few-nucleon systems,[3-7] because in these systems one can hope to keep uncertainties of the conventional nuclear structure small, which tend to cover up such interaction effects in the heavier nuclei.

The simplest system in this respect is the deuteron, which has the advantage that its structure in the nonrelativistic theory is well known. The disadvantage is that the deuteron is a rather dilute system, where interaction effects, which sensitively depend on the density, are expected to play a minor role. And in fact, very recent experimental data[8] on elastic electron-deuteron scattering for rather high momentum transfer up to 150 fm^{-2} seem to indicate the absence of any interaction effects because the conventional theory already gave a satisfactory description.

However, a closer inspection of the situation shows that the deuteron structure function $A(q^2)$, which has been determined in this experiment and which is dominated by the charge and quadrupole form factors, is not sensitive at all to interaction effects,[9,10] as has previously been conjectured by Rand *et al.*,[11] who could describe the existing experimental data for the elastic deuteron structure functions by essentially refitting the magnetic neutron form factor. The reason for this is that the already rather small isoscalar interaction current contributes mainly to the magnetic form factor at high momentum transfers and thus shows up in the magnetic deuteron structure function $B(q^2)$.[10] In addition, the validity for the use of a nonrelativistic theory in that region of momentum transfer is quite questionable.

Therefore, a clearer situation is expected in the study of the isovector interaction current, which is dominated by the pion, in the low and intermediate momentum transfer region, say, up to 20 fm^{-2}. Thus, photodisintegration and electrodisintegration of the deuteron appear more promising. And in fact, not long ago the long standing 10% discrepancy between experiment and theory for thermal n-p capture has been explained almost quantitatively by considering pionic MEC and IC.[3] Also in the reaction $d(\gamma,p)n$ a significant improvement at higher energies is achieved.[4]

Even larger effects show up in the electrodisintegration of deuterium[5,6,11] at low excitation energies but higher momentum transfers, where the dominating normal magnetic form factor falls off quite rapidly; the relative importance of the shorter-ranged interaction current increases drastically and eventually becomes dominant above $\vec{q}_{c.m.}{}^2 = 4\ fm^{-2}$. In this region of energy and momentum transfer, the largest contribution comes from the π MEC while the IC are relatively less important.

Theoretical calculations for low excitation energies are in good agreement with experiment if both the π MEC and the IC are included.[5,6] However, the existing body of experimental data[12] is too small to make a more detailed investigation possible, particularly for the higher excitation energies where theoretical calculations are now available.[6]

The aim of the present experiment was, therefore, to provide experimental data on the electrodisintegration of deuterium over a wider range of energy and momentum transfers and to compare these with very recent theoretical results including contributions from the MEC and IC.

The experiment was performed at the Mainz 300-MeV electron linac under conditions similar to those of Ref. 13. The target was a cylindrical cell (12-μm thin Capton walls) filled with liquid deuterium. The hydrogen content was less than 1%. The experimental points were taken with a double-focusing 180° spectrometer at different incident energies between 80 and 300 MeV at angles from 30° to 120°. The scattered electrons were recorded by a 75-channel ladder counter system with a total momentum acceptance of 7.5%. For each setting the magnetic field of the spectrometer was changed step by step to accept the whole inelastic electron spectrum. In this way we measured the energy transfers up to 116 MeV corresponding to relative energies E_{np} of the outgoing protons and neutrons up to 80 MeV. A typical spectrum is shown in Fig. 1.

In addition we measured the elastic e-d cross section at each run with a second spectrometer installed at a fixed angle of 28°. The counting rate of this spectrometer was used during each

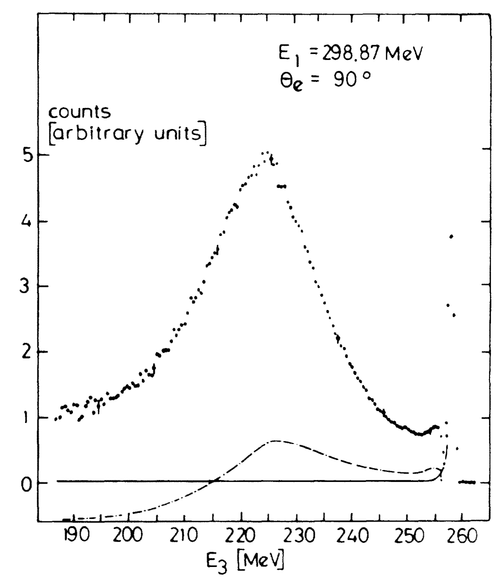

FIG. 1. The spectrum of electrons scattered elastically and inelastically from the deuteron for an incident energy E_1 of 298.87 MeV and a scattering angle θ_e of 90°. The error bars indicate the statistical error. The solid line gives the calculated radiative tail of the elastically scattered electrons; the dash-dotted line indicates the total inelastic corrections.

run as a monitor for changes in target density due to beam-heating effects at high beam currents. Under the same experimental conditions we have also measured, at each energy, the absolute cross section of the elastic e-p scattering to normalize the e-d data points.

The data were corrected for empty target background and for elastic e-p scattering contributions which were noticeable near the maximum of the inelastic e-d spectrum. After these corrections we subtracted the radiative tail of the elastic e-d scattering. The tail was calculated under the assumption of one-photon exchange and for single-photon emission according to the formulas given by Tsai.[14] We have taken into account the straggling caused by target bremsstrahlung and ionization loss. For the angle-peaking approximation, we have used the method of equivalent radiators, which looks similar to the expression for target straggling. Furthermore, the cross section for single-photon emission was corrected for multiple soft-photon radiation.

After the subtraction of the elastic radiative tail from the inelastic e-d spectrum, we applied the radiative corrections for the continuum according to the equivalent radiator method, described by formula C.23 of Ref. 14. These corrections are also indicated in Fig. 1.

Figures 2 and 3 show for two examples the experimental cross sections obtained and the theoretical predictions. The error bars include both statistical and systematical errors. In the theoretical calculations the Hamada-Johnston nucleon-nucleon potential[15] was used for both the bound and the continuum states. Multipoles up to $L=6$ have been included. The interaction effects have been calculated according to Ref. 6. For both 30° and 90° electron deflection angles, there is very good agreement between experiment and theory as long as the interaction effects are taken into account. One sees most clearly that these interaction effects are most important near the threshold and for large momentum transfers, leading to an increase in the cross section of about 60% in the region of the $^1S_0$ resonance near the threshold ($E_{np}<0.5$ MeV) at $\vec{q}_{c.m.}{}^2=3.96$ fm^{-2}, which even shows up as a little bump (see Fig. 3). This drastic enhancement of the cross section is due mostly to the pionic MEC, while the IC play only a minor role (the relative contribution here of the IC is about 20% of MEC). With rising E_{np} however, both interaction effects decrease first and amount to less than 2% near the maximum of the cross section (quasielastic peak). Above this maximum the interaction effects increase again, mostly because of the IC (e.g., at $E_{np}=80$ MeV the total correction is 13%).

The reason for which meson effects show up mostly at large angles and near the threshold is the following one: For small angles, the kinematic function $V_{\text{trans}}(E_1,\theta)$ leads to a significant sup-

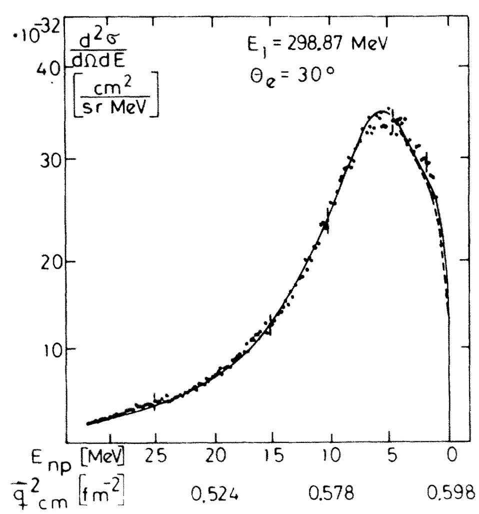

FIG. 2. The double differential cross section at 30° versus the neutron-proton relative energy E_{np}. The corresponding momentum transfer is also indicated. The error bars include both the statistical and systematical errors. The theoretical calculation with (without) the interaction effects is given by the solid (dashed) line.

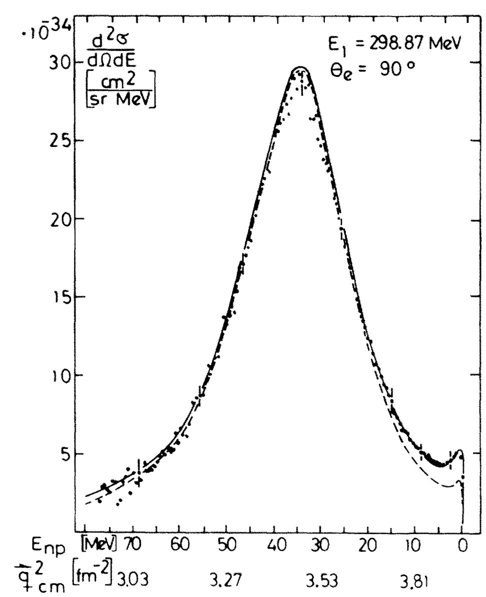

FIG. 3. Same as Fig. 2, but for a scattering angle of 90°.

pression of the transverse form factor $f_{\text{trans}}(\vec{q}_{\text{c.m.}}^2)$ as compared to the longitudinal one. $f_{\text{long}}(\vec{q}_{\text{c.m.}}^2)$, however, is not affected by meson-exchange effects in the lowest order but only by the IC, the latter leading to small enhancements of less than 5% in $f_{\text{long}}(\vec{q}_{\text{c.m.}}^2)$. However, for energies near threshold, the dominating transition is $M1$. As E_{np} increases, higher Coulomb and transverse multipole transitions become more and more important.[6] This leads to the fact that for the higher excitation energies accessible in the present experiment the interaction effects do not show up significantly within the present accuracy.

The kinematic region of this experiment will be extended in order to extract the longitudinal and transverse form factors. This will be reported elsewhere[16] together with further theoretical calculations using different potentials. We expect that, in analogy to photodisintegration, more detailed information can be obtained by measuring the proton angular distribution in coincidence with the scattered electron. At present, we are exploring the possibility of performing such an experiment.

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