DEUTERIUM ELECTRODISINTEGRATION AT HIGH RECOIL MOMENTUM

G. VAN DER STEENHOVEN
Nationaal Instituut voor Kernfysica en Hoge-Energiefysica
P.O. Box 41882, 1009 DB Amsterdam, The Netherlands

ABSTRACT

The availability of continuous electron beams extracted from the Amsterdam Pulse Strecher (AmPS) made it possible to carry out various deuterium electrodisintegration experiments in kinematical domains corresponding to a high recoil momentum. Three such experiments are discussed: (i) the left-right asymmetry with respect to the direction of the momentum transfer has been measured with good precision, which will possibly enable a distinction between different prescriptions of the current operator for deuterium electrodisintegration; (ii) cross sections have been obtained in a kinematical region well above the quasi-elastic peak, which serve as testing ground for the treatment of Δ-currents in deuterium electrodisintegration; (iii) data have been taken in quasi-elastic kinematics that can be used to study high-momentum components in the deuterium wave function.

1. Introduction

Deuterium electrodisintegration data give access to the nucleon momentum distribution of the simplest nuclear system. Various calculations are available of the corresponding nucleon wave function[1,2,3,4], which are all in good agreement with existing data[5] provided that the Final-State Interaction (FSI) is properly treated.

In order to discriminate between the available calculations additional deuterium electrodisintegration experiments are needed focussing on the region of high recoil momentum, i.e. $|\vec{p_r}| \geq 300$ MeV/c. In this domain the calculations differ by up to a factor two[6]. At the same time, however, the influence of FSI-effects, Meson-Exchange-Current (MEC) effects, Isobar Currents (IC) and Relativistic Corrections (RC) of the current operator are becoming increasingly important. Hence, separate experiments are needed in kinematical conditions that emphasize any of the aforementioned effects. In this paper three such investigations are discussed, each of them focussing on a different aspect of the reaction: (i) relativistic effects; (ii) Δ-currents; and (iii) high-momentum components.

2. Experimental method

The experiments have been performed using the Amsterdam Pulse Stretcher[7] (AmPS) at NIKHEF. Semi-continuous electron beams of about 2 μA with a duty factor of typically 50% were employed in the present experiments. A newly constructed liquid deuterium target[8] of about 240 mg/cm^2 thickness was used. The scattered electrons were detected by one of the existing high-resolution magnetic spectrometers[9], while the emitted proton is either detected by the second spectrometer available (experiment (i)), or by a large-solid angle segmented scintillator detector[10], labeled 'Hadron-4' (experiments (ii) and (iii)).

In order to explain the kinematical differences between the various measurements that have been performed, we start from the general one-photon-exchange expression of the cross section for deuterium electrodisintegration[11]:

$$\frac{d^5\sigma}{d\omega^{\rm lab} d\Omega_{\rm e}^{\rm lab} d\Omega_{\rm np}^{\rm c.m.}} = C\left(\rho_{00}f_{00} + \rho_{11}f_{11} + \rho_{01}f_{01}cos\phi_{\rm np} + \rho_{-11}f_{-11}cos2\phi_{\rm np}\right). \quad (1)$$

The four structure functions f_{00}, f_{11}, f_{01} and f_{-11} contain information on the dynamics of the system. The out-of-plane angle $\phi_{\rm np}$ represents the angle between the electron scattering plane, and the plane defined by the momentum transfer $\vec{q}$ and the momentum $\vec{p}'$ of the outgoing proton.

It was shown by Mosconi and Ricci[4] that f_{01} is very sensitive to relativistic corrections of the electromagnetic current, while f_{-11} can obtain large contributions from the Δ currents[11]. Experimentally, the structure function f_{01} can be determined by measurements performed at $\phi_{\rm np} = 0$ and π. Such data are usually presented in terms of the asymmetry A_ϕ:

$$A_\phi \equiv \frac{\sigma(0) - \sigma(\pi)}{\sigma(0) + \sigma(\pi)} = \frac{\rho_{01}f_{01}}{\rho_{00}f_{00} + \rho_{11}f_{11} + \rho_{-11}f_{-11}}, \quad (2)$$

where $\sigma(\phi_{\rm np})$ represents the 5-fold differential (e,e'p) cross section of Eq. (1). Asymmetries are not dependent on the normalization of the experiment, and only weakly dependent on deuteron structure[12]. Hence, the value of A_ϕ is largely determined by the electromagnetic current and its various ingredients, such as RC-, MEC- and IC-effects[13].

An unambiguous determination of f_{-11} requires out-of-plane measurements at $\phi_{\rm np} = \frac{1}{4}\pi$, $\frac{1}{2}\pi$ and $\frac{3}{4}\pi$, for instance[14]. In practice, it is sufficient to perform measurements at considerably smaller values of $\phi_{\rm np}$. At NIKHEF, for instance, measurements have been performed at $\phi_{\rm np} \approx \pi$, $\pi + \frac{1}{9}\pi$ and $\pi - \frac{1}{9}\pi$. In that case[15] one may evaluate the quantity σ_{TT}:

$$\begin{aligned} \sigma_{TT} &= \sigma(\pi) - \tfrac{1}{2}[\sigma(\pi + \tfrac{1}{9}\pi) + \sigma(\pi - \tfrac{1}{9}\pi)] && (3)\\ &= C\{[1 - cos(\tfrac{2}{9}\pi)]\rho_{-11}f_{-11} - [1 - cos(\tfrac{1}{9}\pi)]\rho_{01}f_{01}\}. && (4)\end{aligned}$$

Explicit calculations show that σ_{TT} is largely dominated by the f_{-11} term provided that the kinematics are chosen close enough to the region of the Δ-resonance[15].

The three ^{2}H(e,e'p) experiments that were recently performed at AmPS include measurements of A_ϕ, σ_{TT} and the Q^2 dependence of the cross section at high recoil momentum.

3. The A_ϕ measurements

Existing measurements[12] of A_ϕ are limited in both statistics and kinematics, i.e. $|\vec{p_m}| \equiv |\vec{p_r}| \leq 170$ MeV/c. As a result the data cannot distinguish between the covariant calculations of Tjon et al.[2] and those that only include a relativistic correction to order $\frac{1}{m^2}$ of the current operator[4]. A new experiment[16] has been performed at AmPS which may enable such a distinction. Data have been collected at a beam energy of 604 MeV, a Q^2-value of 0.2 (GeV/c)^2, and central p_m-values of 175 and 194 MeV/c.

The measured values of A_ϕ are shown in fig. 1 together with those of ref. 17. Note that the data have not yet been corrected for finite acceptance effects[17]. The new data confirm earlier findings[12,17] that A_ϕ cannot be described in an entirely non-relativistic framework, thus removing any remaining uncertainty related to the interpretation of the A_ϕ data as was mentioned in ref. 18. Moreover, the preliminary data exhibit a stronger asymmetry than predicted by either of the calculations[2,4] shown in fig. 1. This large asymmetry is suggestive of additional current-conserving effects as proposed by Nagorny et al.[13] that predict large asymmetries, i.e. $|A_\phi| \geq 0.4$, beyond 160 MeV/c.

4. The σ_{TT} measurements

In order to measure σ_{TT} data have been collected at $E_0 = 525$ MeV using both a magnetic spectrometer and the aforementioned Hadron-4 detector[10]. The large out-of-plane acceptance of the Hadron-4 detector enabled such measurements. However, for a good determination of σ_{TT} the relative efficiency of the various scintillators of Hadron-4 needs to be precisely known. At the time of the conference the efficiency calibration had not been completed. Hence, only some qualitative features of the ^{2}H(e,e'p) cross section data can be discussed.

The kinematics of the experiment were centered in the region of the Δ-resonance, at $W = 1232$ MeV and $Q^2 = 0.03$ (GeV/c)^2. Preliminary cross sections have been determined and were compared to non-relativistic calculations of Leidemann[19]. The calculations largely underestimate the data as long as the effect of the Δ-resonance is not taken into account. By including the isobar currents the calculation is much closer to the data. The final cross section and σ_{TT} data, which will be available soon, are thus expected to be highly sensitive to a proper treatment of Δ-effects in the reaction ^{2}H(e,e'p).

5. Measurements at high recoil momenta

With the constraints provided by the A_ϕ and σ_{TT} measurements it will be possible to perform quite reliable deuterium electrodisintegration calculations that can be applied to the study of high momentum components of the deuteron wave

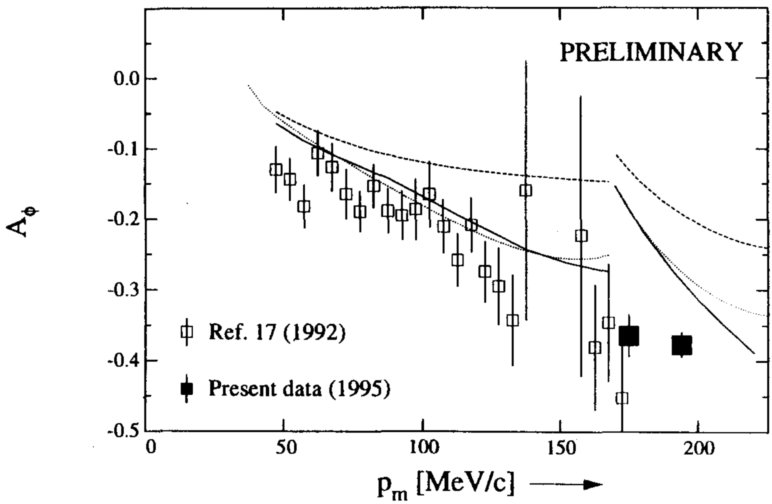

Figure 1: **Preliminary data (solid squares) for the asymmetry A_ϕ measured at $Q^2 = 0.2$ $(GeV/c)^2$. The existing data of ref. 17 are represented by the open squares. The solid and dashed curves represent the covariant and non-relativistic calculations due to Hummel and Tjon[2], and Arenhövel[1], respectively. The dotted line corresponds to a non-relativistic calculation with $\frac{1}{m^3}$-corrections in the current operator due to Mosconi[4]. As the kinematics used in ref. 17 differ from the ones presently employed, the curves are discontinuous at p_m = 165 MeV/c.**

function. Measurements[16] of the high-momentum part of the the reaction ^{2}H(e,e'p) have been performed using the 15 msr QDQ electron spectrometer and the 500 msr Hadron-4 detector[10]. Data have been collected at a constant invariant mass W of 1050 MeV, beam energies of 525 and 576 MeV, and Q^2-values of 0.1, 0.2 and 0.3 $(GeV/c)^2$.

The large acceptance of the Hadron-4 detector made it possible to cover a large p_m-range in only 2 angular settings (at each Q^2 value). This is illustrated in figure 2, in which the expected count rate is shown for each Q^2 value covered in the experiment. The high count rate per 25 MeV/c p_m-bin allowed for very modest running times, i.e. $\leq$ 16 hours per setting. As the data analysis is still in progress, no final data are yet available. Nevertheless, several remarks can be made.

- The invariant mass has been chosen to be close to the value of W corresponding to the quasi-elastic peak in order to minimize MEC- and IC-contributions. Other recent ^{2}H(e,e'p) experiments focussing on the high p_m range have been performed at considerably larger W values[20].
- The Q^2 dependence serves as an additional constraint on the reaction mech-

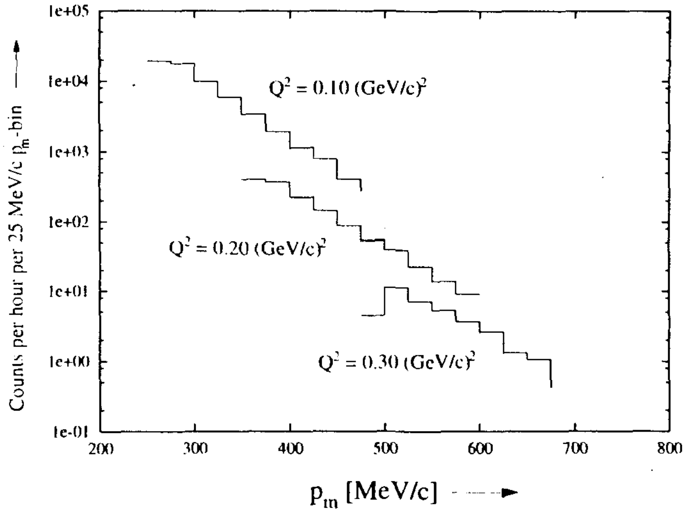

Figure 2: Expected count rate for the $^{2}H(e,e'p)$ experiment that was recently performed at the AmPS facility. The calculations assume an average beam current of 5 μA, a target thickness of 250 mg/cm^2 and the detector solid angles mentioned in the text. The three Q^2-regions covered by the experiment are indicated.

anism at high recoil momentum. Further constraints could be derived from a separation of f_{00} and f_{11} under these conditions. However, a longitudinal-transverse separation at high-recoil momentum requires the availability of beam energies beyond 1 GeV (and very small detector angles).

- The on-line analysis of the data showed a significantly higher count rate (by typically a factor of two) at high recoil momenta, as compared to the count-rate estimates displayed in figure 2. These estimates were based on the parametrization of Krautschneider[21], which gives a good account of the existing low-p_m data[5]. The interpretation of this observation awaits the final analysis of all experiments described in this paper in order to disentangle contributions from relativistic effect, exchange currents and true high-momentum components in the nuclear wave function.

6. Summary

In this paper first results have been presented of a new series of deuterium electrodisintegration measurements performed at AmPS. Complementary work -not discussed in this paper- has been carried out at Mainz[20], M.I.T./Bates[22], Bonn[23] and SLAC[24], and is foreseen at CEBAF[25].

New preliminary data on the asymmetry A_ϕ provide new evidence in favour of a relativistic treatment of the current operator used to describe the reaction ^{2}H(e,e'p). Out-of-plane measurements performed in the region of the Δ-resonance will provide data on the f_{-11} interference structure function. New high-recoil momentum data have been collected at several values of the momentum transfer squared Q^2, keeping the invariant mass W close to the quasi-free value. It will be highly interesting to compare the momentum distribution derived from this experiment to those obtained in Mainz[20] at higher values of W, and to those deduced from ^{2}H(e,e') and ^{1}H(d,p) experiments[26,27]. Together these data are expected to provide new insights into the short-range structure of the deuteron wave function.

The work presented in this paper is the result of a very fruitful collaboration with many colleagues. In particular I would like to thank Willem Kasdorp and Antonio Pellegrino, whose thesis work is at the basis of sections 3, 4 and 5. This work is part of the research program of the "Stichting voor Fundamenteel Onderzoek der Materie" (FOM), which is financially supported by the "Nederlandse Organisatie voor Wetenschappelijk Onderzoek" (NWO).

References

1. H. Arenhövel, *Nucl. Phys.* **A384** (1982) 287.
2. E. Hummel and J.A. Tjon *Phys. Rev.* **C49** (1994) 21.
3. V.V. Kotlyar, Yu.P. Mel'nik, and A.V. Shebeko, *Phys. Part. Nucl.* **26** (1995) 79.
4. B. Mosconi and P. Ricci, *Nucl. Phys.* **A517** (1990) 483; and *Few Body Syst.* **Suppl. 5** (1992) 223.
5. M. Bernheim et al., *Nucl. Phys.* **A365** (1981) 349.
6. F. Gross, J.W. Van Orden and K. Holinde, *Phys. Rev.* **C45** (1992) 2094.
7. P.K.A. de Witt Huberts, *Nucl. Phys.* **A553** (1993) 845c.
8. W-J. Kasdorp et al., to be published (1995).
9. C. de Vries et al., *Nucl. Instr. and Meth.* **249** (1984) 337.
10. A prototype is described in: A. Zondervan et al, *Nucl. Instr. and Meth.* **A342** (1994) 436.
11. W. Fabian and H. Arenhövel, *Nucl. Phys.* **A314** (1979) 253.
12. G. van der Steenhoven, *Few Body Syst.* **17** (1994) 79.
13. S.I. Nagorny, Yu.A. Kasatkin and V.A. Zolenko, *Phys. Lett.* **B316** (1993) 231.
14. G. van der Steenhoven, *Few Body Syst.* **Suppl. 5** (1992) 17.
15. NIKHEF Proposal **93-02** (1993); Spokesperson: J.A. Templon.
16. NIKHEF Proposal **91-15** (1991); Spokesperson: G. van der Steenhoven
17. M. van der Schaar et al., *Phys Rev. Lett.* **66** (1992) 776.
18. J.E. Ducret et al., *Phys. Rev.* **C49** (1994) 1783.
19. W. Leidemann and H. Arenhövel, *Nucl. Phys.* **A393** (1983) 385.
20. Mainz Proposal **A1/5-90** (1990); Spokesperson: W.U. Boeglin.
21. F. Krautschneider, Ph. D. Thesis, Bonn University, BONN-IR-76-37 (1976).
22. MIT/Bates Proposal **90-xx** (1990); Spokespersons: W.U. Boeglin and W. Bertozzi.
23. B.H. Schoch, *Few Body Syst.* **Suppl. 7** (1994) 144.
24. J.F.J. van den Brand, *Few Body Syst.* **Suppl. 7** (1994) 151.
25. CEBAF Proposal **PR 93-041** (1993); Spokesperson: P.E. Ulmer.
26. I. Sick, D. Day and J.S. McCarthy, *Phys. Rev. Lett.* **45** (1980) 871.
27. V. Punjabi et al.,*Phys. Rev.* **C39** (1989) 608.