ELECTRON SCATTERING OFF TENSOR-POLARIZED DEUTERIUM

C.W. de Jager, for the 91-12 collaboration

National Institute for Nuclear Physics and High-Energy Physics, section K (NIKHEF-K)
P.O. Box 41882, 1009 DB Amsterdam, The Netherlands

Invited talk presented at the 7th Conference on Perspectives in Nuclear Physics at Intermediate Energies, 8-12 May, 1995, International Centre for Theoretical Physics, Trieste, Italy.

This is a preprint of a paper intended for publication in a journal or proceedings. Because changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without permission of the author(s).
ELECTRON SCATTERING OFF TENSOR-POLARIZED DEUTERIUM

KEES DE JAGER, FOR THE 91-12 COLLABORATION a
NIKHEF, P.O. Box 41882, 1009 DB Amsterdam, The Netherlands

ABSTRACT

An experiment is described which measures the spin dependence of the (e,e'd) and (e,e'p) reaction for polarized deuterium and unpolarized electrons, using the Internal Target Facility at the Amsterdam Pulse stretcher ring at NIKHEF. Tensor-polarized deuterium is produced in an atomic beam source and injected into a storage cell. The low-background conditions allowed the use of large-acceptance non-magnetic detectors for the electron-proton (-deuteron) coincidence measurements. The use of several polarimeters and other diagnostic tools have resulted in absolute measurements of the tensor-analyzing powers. First results, both for the elastic channel as well as for the quasi-elastic one, are presented.

1. Introduction

Electron-scattering experiments off polarized internal targets are now being carried out or contemplated at a number of intermediate- and high-energy facilities. Polarized internal targets offer several advantages such as high polarization, no dilution due to unpolarized species, rapid reversal of polarization, while requiring only a relatively low holding field. These targets, in conjunction with both the high available currents in storage rings and suitable large-acceptance detectors, provide a powerful tool to explore the spin degrees of freedom in electron scattering from nuclei. With the construction of the Amsterdam Pulse Stretcher ring AmPS, the NIKHEF facility has also been expanded with an Internal Target Facility. The performance of the storage ring has been described elsewhere1. The first internal-target experiment performed at NIKHEF-K investigated the spin dependence in elastic and quasi-elastic scattering of unpolarized electrons from tensor-polarized deuterium.2

Tensor-polarized deuterons are produced in an atomic beam source3 and injected into a storage cell. Two large-acceptance non-magnetic detectors are used for the electron-proton (-deuteron) coincidence measurements. After a short description of the experimental set-up, this paper will present the results of several performance tests. An important aspect in polarization experiments is a reliable determination of the degree of polarization. The use of several polarimeters and other diagnostic tools result in absolute

---

measurements of the tensor-analyzing powers. First results, both for the elastic channel (which measures the $T_{20}$ analyzing power) as well as for the quasi-elastic one, are presented.

2. Experimental set-up

2.1 General description

The polarized deuterium target consists of an open-ended storage cell of 40 cm length, made from aluminum. The target was fed by an atomic beam source (ABS). The detector system consists of a calorimeter for the detection of the scattered electrons and a range telescope for detection of the knocked-out protons and recoiling deuterons.

![Figure 1. Overview of the NIKHEF internal target set-up, showing the target cell (central part of the figure), the Atomic Beam Source (at the left), the Range Telescope (upper detector) and the Calorimeter (lower detector).](image)

The calorimeter (CM) is composed of six layers, each containing 10 CsI(Tl)-crystals of dimensions 6x6x15 cm$^3$, and two plastic scintillators, respectively 5 and 1 cm thick; the scintillators are used to define the trigger signal. It is positioned at a central scattering angle of 35°, the solid angle covers 130 mrad. The range telescope (RT) contains 16 layers of plastic scintillator material. The first layer has a thickness of 2 mm, so that it will be traversed by low-energy recoiling deuterons, the following layers are 10 mm thick. The central scattering angle of the RT is 80°, the solid angle amounts to 300 mrad. Both detector arms are equipped with two sets of multi-wire proportional chambers in order to reconstruct the particle tracks. The complete set-up is shown in fig. 1.

2.2 Performance tests

The experimental set-up has been tested extensively. In January 1994 the first measurements were performed with an electron beam of 28 mA at an energy of 508 MeV. A storage cell of 40 cm with a diameter of 20 mm made out of 0.1 mm thick ultra-pure aluminum, coated with teflon, was used. This experiment allowed a performance test of the atomic beam source, the range telescope and the calorimeter with the associated electronics. Background studies showed that a considerable fraction of the background
was caused by the beam halo. The ABS showed a large RF leakage from the dissociator, causing problems in several electronic units, especially in the read-out electronics of the wire chambers. Based on the experience acquired during these tests several improvements in the system have been made. Installation of a slit system in the opposite straight of the storage ring allowed a reduction of about an order of magnitude in the background rate, while hardly affecting the lifetime of the beam. Furthermore it was decided to build a new dissociator.

A further test of the system has been performed in June 1994 when the system was tested with unpolarized deuterium and hydrogen gas to obtain a good energy and position calibration of the detector system. In this stage a 15 mm diameter storage cell made from 25 \( \mu \)m aluminum was used. The energy of the stored electrons was 565 MeV.

The synchrotron radiation losses in the stored electron beam are compensated for by a 476 MHz cavity in the AmPS storage ring. By stacking several beam pulses out of the MEA accelerator currents of up to 80 mA were obtained. The density of the beam decayed exponentially with decay times in excess of 1000 s.

Figure 2 shows the reconstructed position of the interaction point along the target cell. The expected triangular density distribution is apparent. The asymmetry in the distribution reflects the angular dependence of the Mott cross section and phase space factors. The shaded area indicates the background measured without gas in the storage cell.

![Figure 2. Reconstructed vertex position for (e,\( \gamma \)p) coincident events along the target cell. The shaded area indicates the background measured with an empty target cell.](image)

For experiments with polarized deuterium a reasonably strong (30 mT) holding field is required. The vertical component of this field will cause a deviation of the trajectory of the stored electron beam from its closed orbit. Therefore a compensation magnet has been constructed; with additional slight adjustments of several correction magnets in the ring the effect of the holding field could be completely compensated.

Important for the functioning of the detectors are the single rates in the various detector parts. The main part of the single rates consists of low-energy particles, like Møller electrons and photons and electrons from electromagnetic showers, produced by electrons in the beam halo. The only shielding from the target used in the experiment was a 2 mm layer of aluminum in front of the CM vertex wire chamber. This shielding
diminished the rates in the CM wirechambers significantly. During injection of beam pulses into the AMPS-ring the high voltage on all wire chambers was lowered by 500 V. In table 1 single rates in some detector parts are listed. The contribution from the gas in the storage cell and the background contribution are listed separately. The presented data were measured at a beam current of 50 mA. The single rates are a linear function of the gas flow to the storage cell, which is expected since the target thickness is proportional to the gas flow to the storage cell. The large difference between the rates in the first and in the second layer of both the CM and the RT indicate the large amount of low-energy particles. The single rates in the first detector layers are suppressed by a factor of two by the target holding field. The rates in the deeper layers are not affected by the holding field, which is additional evidence for the large number of low-energy particles.

Table 1. Single rates in the various detectors. Numbers are normalized to beam current. Units for the background contribution are Hz/mA and for the gas contribution Hz/mA/10^{16} at s^{-1}. The gas flow is into a 400 mm long storage cell with a diameter of 15 mm. Count rates in the wirechambers are given per wire.

<table>
<thead>
<tr>
<th>Detector part</th>
<th>count rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>background</td>
</tr>
<tr>
<td>Range Telescope layer #1</td>
<td>744</td>
</tr>
<tr>
<td>Range Telescope layer #2</td>
<td>130</td>
</tr>
<tr>
<td>Calorimeter scintillator #1</td>
<td>536</td>
</tr>
<tr>
<td>Calorimeter scintillator #2</td>
<td>32</td>
</tr>
<tr>
<td>Calorimeter arm triggers</td>
<td>3.2</td>
</tr>
<tr>
<td>Range Telescope Wire Chamber</td>
<td>470</td>
</tr>
<tr>
<td>CM vertex Wire Chamber</td>
<td>900</td>
</tr>
</tbody>
</table>

3. Experimental results

In December 1994 the improved ABS was put into operation. The RF leakage has been strongly reduced; also the polarization was much more stable than before. An electron beam of 570 MeV out of MEA was stored in the AmPS ring. By stacking several beam pulses stored currents of over 100 mA were obtained. The beam lifetime exceeded 1000 s. By cooling the 15 mm storage cell to 80 K a target thickness of 2\times10^{13} atoms/cm^{2} was obtained, corresponding to a luminosity close to 10^{31} cm^{-2}s^{-1}. A holding field of 30 mT was used. Data were taken with the direction of the target polarization
parallel and perpendicular to the direction of the momentum transfer. The target tensor polarization was flipped between +1 and -2 every 10 s.

At regular intervals during the experiment the ABS was shut off, and molecular hydrogen was flowed into the target so that $^1\text{H}(e,e'p)$ elastic measurements were carried out. These measurements served to calibrate the time-of-flight system, monitored the stability of the electronics, and provided information on the background rate. Furthermore, measurements with an empty target were performed periodically to obtain information on background events.

An important requirement is a good knowledge of the polarization of the deuterons in the cell. In the first place the performance of the ABS has to be known. In the cell there are several mechanisms that might affect the target polarization. The power, delivered by the 476 MHz cavity in the ring, might cause depolarization through electron spin-flip resonances. Furthermore, recombination of the polarized atoms by wall collisions in the storage cell is a well-known source of depolarization. Polarimetry is therefore essential for a proper interpretation of the data. Using on-line results from a Breit-Rabi polarimeter and the separation of the atomic and molecular fractions in combination with off-line results obtained with a tritium polarimeter resulted in an absolute determination of the polarization of 42±7 %.

The consistency of the polarization measurements is confirmed by the first results of the data analysis. Electrons scattered elastically through 30° in the CM were detected in coincidence with recoiling deuterons at 65°. The angular correlation between the electron and the deuteron, the timing and the pulseheight of the signals in the first two layers of the RT (2 mm and 10 mm plastic, respectively) resulted in a clear separation of protons from deuterons. The obtained value for the tensor polarization $T_{20}$ is shown in fig. 3.

![Graph](image)

Figure 3. Experimental results and theoretical predictions for the tensor analyzing power in elastic e-d scattering $T_{20}$. The references for the curves and data are given in ref. 6, except for Bonn (1991)$^7$ and VEPP-3 (1992)$^8$. 
Previous internal-target experiments in the VEPP-3 storage ring\textsuperscript{9} missed the tools to measure the target polarization. Therefore, the data were binned into two momentum-transfer bins. Then the low-\(q\) datum was normalized to a theoretical prediction, and the resulting normalization used in the other datum. In the present experiment we performed an absolute measurement. The analysis of the elastic scattering resulted in a data point of \(T_{20}\) which is in excellent agreement with the world set of data. The small error bar on the present data point, obtained in a very limited amount of beam time, is a clear indication of the powerful capabilities of internal experiments at NIKHEF. Further measurements of \(T_{20}\) extending to \(q\)-values up to nearly 5 \(\text{fm}^{-1}\) will be performed in the near future.

![ABS/nogas and Asymmetry plots](image)

Figure 4. Preliminary results for the break-up channel as a function of the out-of-plane angle between the scattered electron and the knocked-out proton. The left figure shows the event ratio with the ABS on and without gas in the storage cell, the right one the tensor asymmetry with the holding field perpendicular to the momentum-transfer vector. The curves are predictions by Arenbövel and Leidemann\textsuperscript{10}: dashed PWIA, full PWIA+FSI+MEC.

The results for the tensor-analyzing power in the quasi-elastic (e,e'p) reaction are shown in fig. 4. Events originating from the aluminum walls of the storage cell show a completely different \(p_m\)-dependence than actual scattering events from the polarized deuterium. As a result the contribution from the cell walls increases strongly with the missing momentum \(p_m\). In fig. 4 this ratio is shown as a function of the out-of-plane angle. This effect was corrected for in the results shown for the tensor-analyzing power. These results are in excellent agreement with calculations by Arenbövel et al\textsuperscript{10}.

4. Conclusions

It was shown that the Internal Target Facility at NIKHEF is capable to perform experiments with polarized targets with high accuracy. Background conditions allow the use of non-magnetic detectors. The different polarization measurements yield an
absolute determination of the target polarization. Both results on elastic as well as quasi-
elastic scattering have been obtained with unprecedented accuracy, clearly showing the
powerful capabilities of the Internal Target Facility at NIKHEF.

5. Acknowledgements

This work was supported in part by the Stichting voor Fundamenteel Onderzoek
der Materie (FOM), which is financially supported by the Nederlandse Organisatie voor
Wetenschappelijk Onderzoek (NWO), NWO under Grant 713-119 (Novosibirsk), the
EEC Human Capital and Mobility program under Grants no. ERBCBHICT-930606,
CHR XCT-930122 and ERB4001GT-931472, the National Science Foundation under
Grants no. PHY-9316221 (Wisconsin), PHY-9200435 (Arizona) and HDR-9154080
(Hampton), NATO under Grant no. CRG920219 and the Swiss National Foundation.

6. References

1. T. Botto et al., in *Proc. of the International Workshop on Polarized Beams and
2. NIKHEF-K Proposal 91-12, spokespersons J.F.J. van den Brand and C.W. de
Jager.
*Nucl. Instrum. and Meth.*
4. H.J. Bulten et al., in *Proc. of the International Workshop on Polarized Beams and
Polarized Gas Targets*, Cologne, June 6-9, 1995; Z.-L. Zhou et al., to be
submitted to *Nucl. Instr. and Meth.*
5. E. Passchier et al., to be submitted to *Nucl. Instr. and Meth.*
8. S.G. Popov, private communication.
10. H. Arenhövel, private communications; see also H. Arenhövel, W. Leidemann