ELECTRON SCATTERING OFF TENSOR-POLARIZED DEUTERIUM

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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 direct measurements of the tensor analyzing powers. First results, both for the elastic reaction as well as for the quasi-elastic one, are presented.

Introduction

Electron-scattering experiments off polarized internal targets are at present 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 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 extended with an Internal Target Facility. The performance of the storage ring has been described in another contribution to this workshop1. The first internal-target experiment performed at NIKHEF-K investigated the spin-dependence in the elastic and quasi-elastic scattering of unpolarized electrons from tensor-polarized deuterium2. Tensor-polarized deuterons are produced in

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an atomic beam source\(^3\) 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 direct measurements of the tensor analyzing powers.\(^4\) First results, both for the elastic reaction (which measures the $T_{20}$ analyzing power) as well as for the quasi-elastic one, are presented.

**Experimental set-up**

The tensor-polarized deuterium target consists of an open-ended storage cell, fed by an atomic beam source (ABS). The detector system\(^5\) consists of a calorimeter (CM) for the detection of the scattered electrons and a range telescope (RT) for detection of the knocked-out protons and recoiling deuterons. The CM is composed of six layers CsI(Tl)-crystals, each consisting of 10 blocks with dimensions $6 \times 6 \times 15$ cm\(^2\), and two plastic scintillators with a thickness of
5 and 1 cm, respectively; the scintillators are used to define the trigger signal. It is positioned at a central scattering angle of 35°, the solid angle covers 130 msr. The 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 msr. Both detector arms are equipped with two sets of multi-wire proportional chambers in order to perform the required track reconstruction. The complete set-up is shown in fig. 1.

**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 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. A large RF leakage from the dissociator of the ABS caused problems in several electronic units, especially in the read-out electronics of the wire chambers. Also the polarization showed sporadic instabilities in the degree of dissociation of deuterium. 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 section 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 μm 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 MEA 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 clearly visible. 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 with no gas in the storage
cell. 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 a couple of correction magnets in the ring the effect of the holding field could be a 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 is due to low-energy particles, like Möller 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 vertex wire chamber at the electron side. 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 was measured at a beam current of 50 mA. The single rates behave linearly as a function of the gas flow to the storage cell, which is expected from the fact that the target thickness is proportional to the gas flow to the storage cell. The results in the table clearly show the predominance of low-energy particles, as can be seen by comparing the rates in the first and in the second layer of the Range Telescope. The single rates in the first detector layers are significantly suppressed by the target holding field, which reduces the rates in the first detector layers by a factor of two. The rates in the deeper layers are not affected by the holding field, which is additional evidence for low energy particles.
Table 1: Single rates in the various detector components. Numbers are normalized to beam current. Units for the background contribution are Hz/mA and for the gas contribution Hz/mA/10^{14}at s^{-1}. The gas flow is into a 400 mm long storage cell with a diameter of 15 mm. MWPC rates are given per wire.

<table>
<thead>
<tr>
<th>Detector part</th>
<th>Countrate</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 scint. 1</td>
<td>536</td>
</tr>
<tr>
<td>Calorimeter scint. 2</td>
<td>32</td>
</tr>
<tr>
<td>Calorimeter arm triggers</td>
<td>3.2</td>
</tr>
<tr>
<td>Wire Chamber CM vertex</td>
<td>900</td>
</tr>
<tr>
<td>Wire Chamber Range Telescope</td>
<td>470</td>
</tr>
</tbody>
</table>

Experimental results

In December 1994 the improved ABS was put into operation. The RF leakage has strongly been reduced; also the polarization was much more stable than before. An electron beam of 570 MeV out of the MEA accelerator was stored in the AmPS ring. By stacking several beam pulses from MEA stored currents of over 100 mA were obtained. The beam lifetime exceeded 1000 seconds. By cooling the 15 mm storage cell to 80 K a target thickness of 2x10^{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 polarization was reversed every 10 seconds. At regular intervals during the experiment the ABS was shut off, and molecular hydrogen was flowed into the target so that 1H(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. Further, 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 might cause depolarization through electron spin-flip resonances. Furthermore recombination of the polarized atoms is a well-known source of depolarization. Polarimetry is therefore essential for a
proper interpretation of the data. Using the on-line results from the Breit-Rabi polarimeter and the separation of the atomic and molecular fractions in combination with the off-line results obtained with a tritium polarimeter resulted in a absolute determination of the polarization of $42\pm7\%$.

The consistency of the polarization measurements is confirmed by the first results of the analysis. Electrons scattered elastically through $30^\circ$ in the CM were detected in coincidence with the recoiling deuterons at $65^\circ$. Both the timing and the pulseheight of the signals in the first two layers of the RT (2 mm and 10 mm plastic, respectively) were used to separate protons from deuterons. The obtained tensor polarization $T_{20}$ is shown in fig. 3. Previous internal target experiments in the VEPP-3 storage ring missed the tools to measure the target polarization. Therefore one datum was normalized to a theoretical prediction, and the other data points were connected to the aforementioned one. 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 our data point, obtained in a very limited amount of beam time, is a clear indication of the powerful capabilities of internal experiments at NIKHEF. An further measurement of $T_{20}$ extended to higher q-values (around 2.25 fm$^{-1}$) will be
performed at the end of this year. Also results have been obtained for the
tensor analyzing power in the quasi-elastic (e,e'p) reaction. These preliminary
data are in good agreement with calculations by Arenhövel et al.

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 measure-
ments yield an absolute determination of the target polarization. Both results
on elastic as well as quasi-elastic scattering have been obtained with unprece-
dented accuracy, clearly showing the powerful capabilities of the Internal Tar-
get Facility at NIKHEF.

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