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LASER-DRIVEN SPIN-EXCHANGE POLARIZED DEUTERIUM TARGET FOR THE VEPP-3 STORAGE RING

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The experiment on elastic and inelastic scattering of 2 GeV electrons by polarized deuterium atoms is in progress at the VEPP-3 storage ring in Novosibirsk[1]. A substantial increase of the luminosity is expected by introducing a high flux laser-driven spin-exchange source of polarized deuterium atoms[2] to feed the storage cell.

The very first experiments with a polarized deuterium target were performed in Novosibirsk in 1985 at the VEPP-2 storage ring at 600 MeV electron energy[3]. A gas jet beam from the polarized atomic beam source[4] (ABS) was used as a target providing a target thickness about 10^{11}at/cm^2.

At present, the Novosibirsk/Argonne/NIKHEF/St.-Peterburg/Tomsk collaboration has been finished the second phase of the experiment at the 2 GeV electron storage ring VEPP-3 with an internal tensor-polarized deuterium target fed by atomic beam source. The VEPP-3 storage ring provides the possibility for measurements at a wide range of momentum transfer. However, the cross section for elastic scattering decreases dramatically with increasing the momentum transfer. To obtain a reasonable statistical accuracy in the

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most interesting region of the momentum transfer requires increasing the target thickness by one to two orders of magnitude.

A substantial increase in the luminosity will be achieved with the use of a novel source of polarized atoms which is based on the optical pumping spin-exchange technique and has been developed[2] at Argonne National Laboratory. Molecular deuterium is dissociated in an RF discharge tube and fed into a drifilm coated optical pumping cell containing potassium vapor. The potassium is optically pumped and polarized by a circularly polarized laser beam in the presence of a high magnetic field. Electron polarization of the potassium is transferred to deuterium atoms by spin-exchange collisions. Then, the atoms travel through a transport tube where they pass through a HF transition region on the way to the target storage cell. The efficiency of such transitions at low magnetic field and in the 20 MHz frequency region was measured and found to be $\varepsilon = 0.92 \pm 0.05$[5]. The efficiency of the transitions 3→5 and 2→6 should be tested in an actual target configuration in addition to the source configuration. High electron polarization (about 80%) has been measured at flow rates 2×10^{17} at/sec and lower values are measured for flow rates exceeding 1×10^{18} at/sec. The parameters of the used and proposed targets are listed at the Table1.

Additional quadrupole lenses will be installed in the straight section of the VEPP-3 ring to provide for loading the electron beam with a small fixed aperture storage cell in the ring. The beta-functions in the straight section of the VEPP-3 are shown in Fig. 1.

In order to minimize the background from ambient atoms and molecules a differentially pumped vacuum chamber has been designed. Two cryopumps, having 2000 l/sec pumping speed each, will be used to pump the large flux of atoms coming out from the cell. In addition, Ti sublimation pumps separated from the cryopumps will serve as a differential pumping station to achieve a suitable vacuum condition in the ring.

The main improvements of the new target are:

- increasing of the figure of merit of the target more than one order of magnitude,
- decreasing of the mass of the storage cell by two orders of magnitude and thereby decreasing the background counting rate coming from the cell,
- decreasing of the background coming from the cell due to the smaller beam size.

The general view of the target system is shown in Fig. 2.

Up to now:

Table 1: Parameters of the three phases of the T_{20} experiment at VEPP-3. P_e – atomic electron polarization, K_{rf} – efficiency of radio-frequency transition unit, K_{dc} – dissociation fraction.

Phase	I	II	III
Polarized deuterium source type	ABS	ABS	LDS
Flux [*atoms/sec*]	$4 \cdot 10^{15}$	$4 \cdot 10^{15}$	$3 \cdot 10^{17}$
P_{zz}	≈ 1	≈ 1	$P_e \cdot K_{rf} \cdot K_{ds} = .8 \cdot .9 \cdot .6 = .43$
Cell type	fixed	movable	fixed
Cell size [mm^3]	$24 \times 46 \times 940$	$9(13) \times 17(21.5) \times 569$	$13 \times 24 \times 400$
t – Visible target thickness [$atoms/cm^2$]	$3 \cdot 10^{11}$	$3 \cdot 10^{12}$	$2 \cdot 10^{14}$
Target P_{zz}	0.6	0.6	0.8· 0.43=0.35
Figure of merit $t \cdot P_{zz}^2$	10^{11}	10^{12}	$2.5 \cdot 10^{13}$
Detector system			S A M E
e^- scattering angle	10° – 20°	20° – 30°	
e^- $\Delta\phi \times N_{syst}$	40° ×4	60° ×2	
registration :			
tracking	yes	yes	
hadron energy	yes	yes	
electron energy	no	yes	
Anti-background scrapers	no	yes	yes
VEPP-3 optics	old	old	new
beam size σ_z/σ_x [mm]	0.35/1.4	0.35/1.4	0.20/0.7

- the vacuum chamber containing a storage cell for polarized atoms was fabricated and pumped. Pressure below 10^{-6} Pa was obtained,
- atomic polarimeter, containing quadrupole magnets and mass spectrometer to measure atomic polarization was manufactured. The beam pressure about 10^{-9} Pa was easily measured by using lock-in technique,
- the distribution of the magnetic field in the holding field and compensating magnets as well as in the magnets for RF transition and pumping cell were measured and found to be satisfactory,
- the line for the laser beam was completed and two watts of the beam power from Ti-Sp laser was obtained.

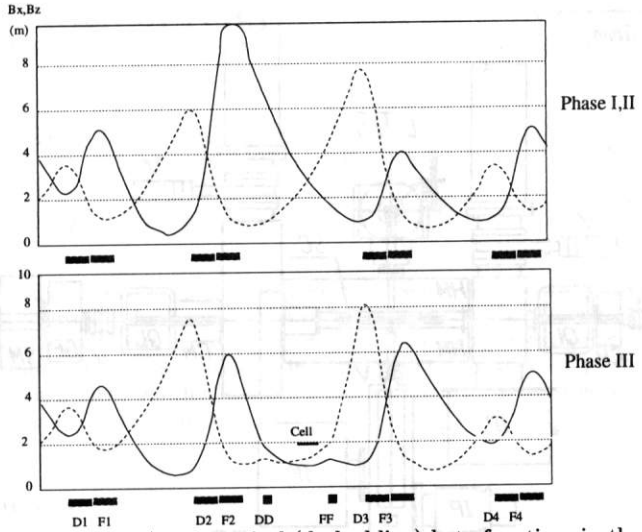

Figure 1: Radial (solid line) and vertical (dashed line) beta-functions in the experimental straight section of VEPP-3, before (upper panel) and after (lower panel) upgrade of the ring optics.

During this fall the straight section equiped by the scrapers to measure the electron beam sizes should be installed into VEPP-3 ring to test new magnetic optics. After the measurement will be completed a storage cell should be installed and test of a detector with unpolarized target should be done.

Acknowledgments

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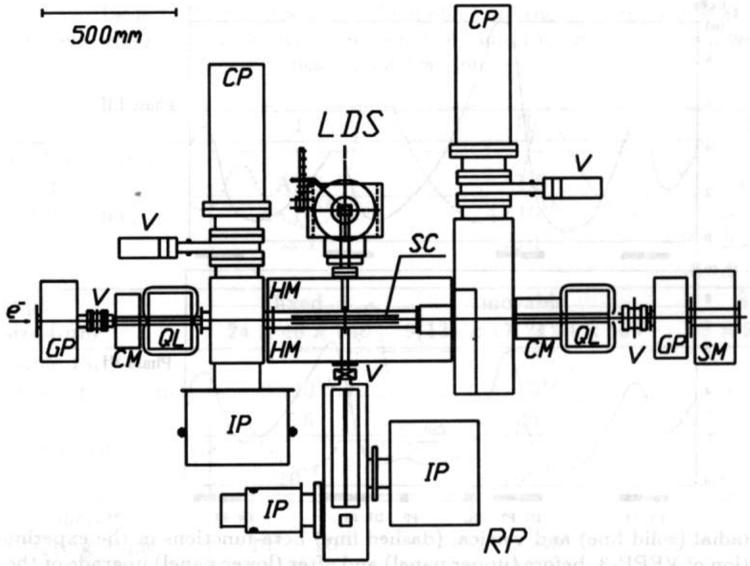

LDS-Laser-Driven Source, SC-storage cell, RP-Rabi polarimeter, HM-holding field magnet, QL-quadrupole Lense,CM-compensated magnet, SM-sextupole magnet, GP-getter pump, CP-cryopump IP-ion pump., V-valve

Figure 2: General view of the target system at VEPP-3

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IMPROVED VERSION OF IONIZER FOR NUCLEAR POLARIZED NEGATIVE ION BEAM PRODUCTION

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Abstract

The enhancement of characteristics of operating nuclear polarized negative ion sources can be reached by simple modification of ionizers, using surface plasma sources for generation of high dense flux of the charge-exchanging negative ions. An additional improvement of nuclear polarized ion beam characteristics can be reached by the transverse extraction of ions from strong magnetic field. Sources of polarized positive ion can be adapted for polarized negative ion production. The features of ionizers useful for enhance of polarization are discussed.

INTRODUCTION

The present status of the nuclear polarized atom and ion sources have been discussed in review [1]. Warm atomic beam with high nuclear polarization from atomic beam source (ABS) can have intensity up to 8×10^{16} atoms/s (13 eq · mA). A spin exchange optically pumped atomic source (OPPAS) can delivered 2×10^{17} atoms/s (30 eq· mA) with 80% atomic polarization and to 2×10^{18} atoms/s with 50% polarization. Up to 6 mA of polarized H^+ has been obtained by resonant charge exchange of polarized H^0 and low energy D^+ in plasma ionizer with arc discharge plasma source and fine grid extraction system [2]. The intensity of nuclear polarized negative ion beam during long time were less than 0.1 mA.

MODIFICATION OF IONIZERS WITH COLLIDING BEAMS

Adaptation of intense polarized proton source [2] for nuclear polarized H^- production has been reached by very simple modification. After inserting of surface -plasma ionizer with cesium catalysis the intensity of extracted H^-

beam were increased from 10^{-7} A to 0.15 mA [3]. By further optimization the intensity is enhanced to 0.6 mA [4]. A high current density beam of D^- or H^- ions from external source can be used for charge - exchange with polarized atoms as in sources with cesium atomic beam ionizer [5]. Different versions of SPS can deliver the necessary intensity of H^- or D^- beam [6], but most adequate for this application is a semiplanatron SPS [6,7]. A beam of H^- or D^- with intensity up to 0.15 A can be obtained from emission slit $0.5\times 10mm^2$ and transformed into parallel beam with 1 cm diameter by focusing bending magnet. It is possible to have up to 50 Hz repetition with pulses 0.5- 1 ms. For injection of this beam into ionizer and for separation and focusing of extracted nuclear polarized negative ions a Y-shaped bending-focusing magnet can be used, as shown in Fig.1. The fine grid multiaperture extraction system [8] can be used simultaneously for extraction of nuclear polarized negative ions and for deceleration of ionizing negative ions from energy 15-20 keV down to 0.1-0.2 keV, optimal for converting nuclear polarized atoms into negative ions. For resonant charge exchange with 0,1 keV H^- cross sections is $\sigma_- = 5\times 10^{15}$ cm^{-2} . For a current density $j^- \approx 0.1A/cm^2$, the estimated increase of the specific efficiency of conversion compared of the cesium beam ionization: $h_-/h_{Cs}=\sigma_- j_-/\Sigma_{Cs} = 10^2$ can be reached. The gas flow from the semiplanotron (SPS) can be strongly separated from ionizer tube by differential pumping. The destruction of nuclear polarized negative ions can be small due to the low density of electrons.

The good space charge neutralization in the ionization region can be reached by good trapping of positive ions during noiseless operation. In the optimal condition it is possible to convert into the extracted beam of negative ions up to 50% of the flow of nuclear polarized atoms. The selective ionization of atoms by resonant charge exchange is very good for the preservation of high degree of polarization.

MODIFICATION OF IONIZER WITH CROSSED BEAMS

Ionizers with transverse injection of primary charge - exchanging negative ion flux will be discussed in this section. The intensity 0.005 mA of H^- is reported in ring magnetron D^- ionizer [9]. The condition for conversion of nuclear polarized cold atoms into polarized negative ions in the ionizer can be improved by using a SPS with low accompanying gas flow. This improvement can be reached by using a SPS with thermoemitter as modified SITEX SPS developed

at ORNL [10]. In this source, the thin sheet of plasma near the converter-emitter is generated by discharge with hot thermoemitter in longitudinal magnetic field. The optimized surface of emitter-converter geometrically focuses

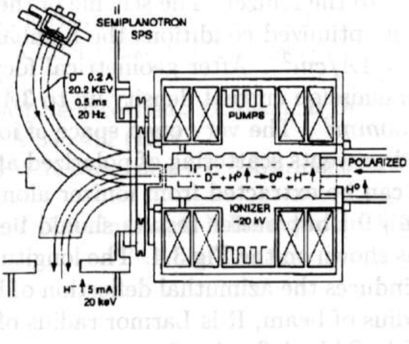

FIG. 1 Schematic diagram of ionizer of polarized H^0 atoms with colliding beam of D^- and axial extraction polarized H^- beam.

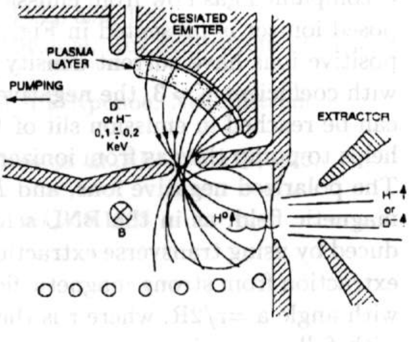

FIG. 2 Schematic diagram of ionizer of polarized H^0 atoms with transverse self-extracted flux of D^- and transverse extraction of polarized H^- beam.

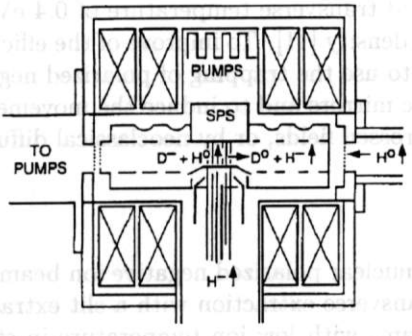

FIG. 3 Schematic of ionizer with transverse ionizing beam and transverse extraction of polarized beam.

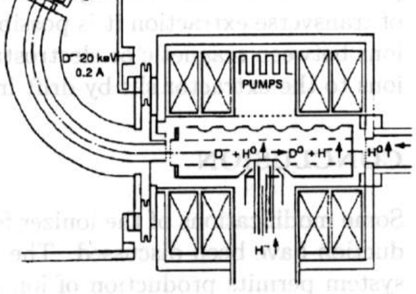

FIG. 4 Schematic of ionizer with longitudinal colliding beam and transverse extraction of polarized beam.

a high flux of negative ions in magnetic field into the emission slit. Additional pumping of the discharge chamber helps to give additional decreasing of accompanied gas flow from emission slit to the ionizer. The scheme of the proposed ionizer is presented in Fig. 2. In optimized conditions the bombarding positive ions have current density $j_- = 1A/cm^2$. After geometrical focusing with coefficient K= 3, the negative ion emission current density up to $3A/cm^2$ can be reached in emission slit of $1 \times 30mm^2$. The very open space of ionizer helps to pump the gas from ionizer and prevents scattering of polarized atoms. The polarized negative ions, and D^- can be extracted from ionizer along the magnetic field, as in the BNL scheme [9] but better results should be produced by using transverse extraction as shown on the Fig.3,4. The longitudinal extraction from strong magnetic field induces the azimuthal deflection of beam with angle a =r/2R, where r is the radius of beam, R is Larmor radius of ions with full energy in max magnetic field. This deflection is not too strong in week magnetic fields but significantly increases emittance in strong magnetic fields, necessary for keeping of the high polarization. For B=1 kG, r = 1cm, the increasing of transverse ion energy is 11 eV. In surface plasma sources of negative ions with transverse extraction, an ion beam with transverse temperature W = 0.18 eV was obtained , and transverse temperature of 0.4 eV was preserved in beams with high current density [11]. To improve of the efficiency of transverse extraction it is possible to use the trapping of polarized negative ions between magnetic or electrostatic mirrors and to induce the movement of ions to the extractor slit by drift in crossed fields, or by neoclassical diffusion.

CONCLUSION

Some modifications of the ionizer for nuclear polarized negative ion beam production have been discussed. The transverse extraction with a slit extraction system permits production of ion beams with low ion temperature in strong magnetic field. By efficient conversion of the fluxes of low energy atoms from ABS and from OPPAS into negative ions, it is possible to have up to 5-15 mA of polarized negative ions with acceptable emittance and with high polarization.

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HIGH-INTENSITY SOURCE OF POLARIZED NEGATIVE HYDROGEN IONS WITH RESONANT CHARGE-EXCHANGE PLASMA IONIZER

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The Moscow INR atomic-beam type source of polarized negative hydrogen ions is described. The H^- ions production is based on charge - exchange of polarized thermal hydrogen atoms and D^- ions in deuterium plasma. Improvements in the D^- plasma source are outlined. The polarized source produces pulsed H^- beam with peak current up to $600\mu A$. Normalized emittance for 90% of beam particles is equal to 1.8π *mm mrad.* The polarimeter of low energy H^- ions is also described. Polarization of the H^- ions was measured to be 0.88 ± 0.01.

1 Introduction

Atomic-beam type polarized hydrogen ion source of Moscow INR produces pulsed beams of polarized H^+ or H^- ions. Resonant charge-exchange reaction between polarized hydrogen atoms and ions in deuterium plasma is used for polarized hydrogen ions production. The source produces H^+ beam with peak current 6 mA, polarization 85%, normalized emittance 2π *mm mrad.* The pulse duration is about 100 μs and repetition rate is up to 25 Hz [1,2].

In order to produce polarized H^- ions in the same source the deuterium plasma has been enriched by D^- ions by use of a specially designed surface-plasma converter. Pulsed H^- ion current 150 μA had been obtained from the source with an early version of the converter [3].

In the framework of participation in SPIN Collaboration [4] we continue to develop more intense source of polarized H^- ions. In this paper we describe general scheme of the H^- source, improved deuterium plasma source, polarimeter of low energy H^- ions and present results of the measurements of the H^- ion beam parameters.

2 Description of the source

Schematic diagram of the source is shown in Fig. 1. Polarized hydrogen atoms are produced by atomic beam apparatus which consists of pulsed rf discharge dissociator, two sextupole magnets and weak field rf transition unit. The atomic beam apparatus is described in details in ref. [1].

The source ionizer works as follows:

The deuterium plasma enriched by D^- ions is generated by the deuterium plasma source with the surface-plasma converter. The polarized atomic hydrogen beam and the deuterium plasma are injected in opposite directions into the charge-exchange region inside the solenoid with magnetic field $\sim 1.3kG$. Polarized H^- ions are formed here due to the charge-exchange reaction:

$$D^- + H^0 \rightarrow D^0 + H^-$$

The cross-section of this reaction is equal to $10^{-14}cm^2$ at D^- ions energy $\sim 20\ eV$ [5].

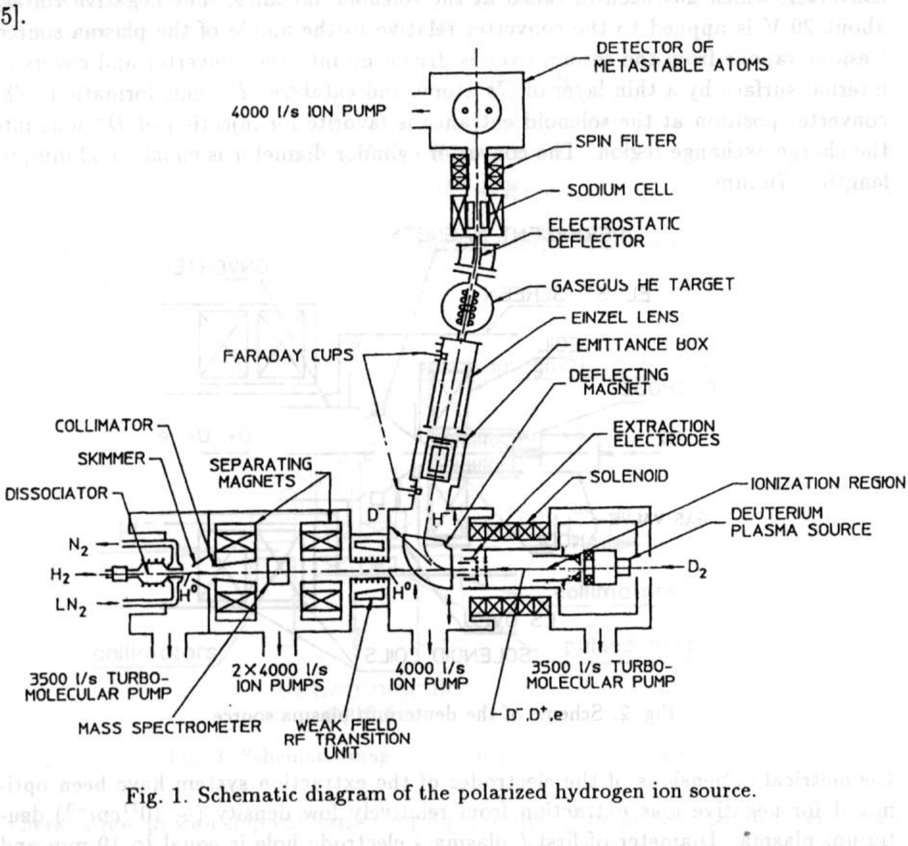

Fig. 1. Schematic diagram of the polarized hydrogen ion source.

Polarized H^- ions formed in this way are confined in radial direction by solenoid magnetic field and then move to the extraction system in which H^- ions are accelerated to an energy $\sim 14keV$ together with D^- ions and plasma electrons. The H^- ions beam is separated from D^- ions and electrons in the deflecting magnet in which H^- beam is deflected for 100^o and extracted from the source.
Intensity of H^- and D^- ions beams is measured by Faraday cups with biased grids installed after the deflecting magnet. The beam emittance is measured by two slits method with electrostatic deflection of H^- ions jet after first slit [6].

Polarization of H^- ions is measured by low energy polarimeter described later in this paper.

The deuterium plasma source has been modified in order to increase D^- density in deuterium plasma inside the charge-exchange region. The modified plasma source is shown schematically in Fig. 2.

The deuterium plasma is generated by an arc-discharge plasma source (see ref. [3]). The plasma passes then through the region with transversal magnetic field $\sim 200\ G$, created by permanent magnets and it is deflected into the internal surface of the converter, which has been installed at the solenoid entrance. The negative voltage about $20\ V$ is applied to the converter relative to the anode of the plasma source. Cesium vapour from the cesium oven is driven up into the converter and covers its internal surface by a thin layer of Cs atoms and catalyzes D^- ions formation. The converter position at the solenoid entrance is favorite for injection of D^- ions into the charge-exchange region. The converter cylinder diameter is equal to 50 mm, its length is 70 mm.

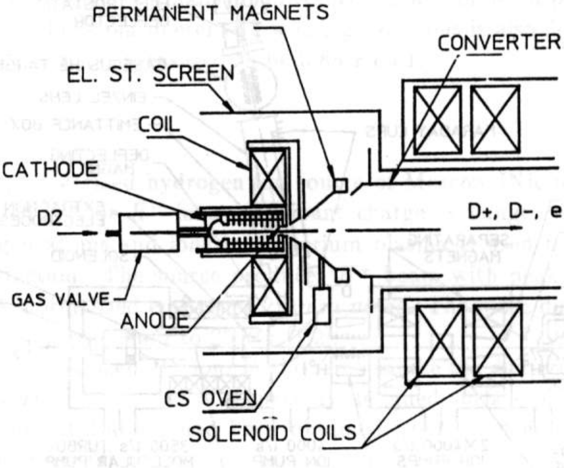

Fig. 2. Scheme of the deuterium plasma source.

Geometrical dimensions of the electrodes of the extraction system have been optimized for negative ions extraction from relatively low density ($\sim 10^{11} cm^{-3}$) deuterium plasma. Diameter of first (plasma) electrode hole is equal to 19 mm and distance between first and second electrodes is equal to 25 mm.

3 Polarimeter

Polarization of H^- ions with energy $\sim 14\ keV$ has been measured by Lyman-alpha polarimeter. The polarimeter has been designed for polarization measurements of H^+ ions. Its design and operation principle are described in ref. [1].

In order to use this polarimeter for H^- ions, the gaseous stripping target has been installed in the beam line upstream the Lyman-alpha polarimeter (see Fig. 1). The stripping target is shown schematically in Fig. 3. The target consists of a stainless-steel tube with 15 mm diameter and 150 mm in length through which the H^- ions beam is passed. Gaseous helium is injected into the target tube in a pulsed mode by the electromagnetic valve. Longitudinal magnetic field up to 2 kG is created by the pulsed solenoid.

The process of H^- ions stripping in the gaseous target can take place either in one step with double loss of electrons by H^- ion or in two steps with consequent loss of single electron by H^- ion and then by H^0 atom:

$$H^- + He \rightarrow H^+ + He + 2e, \tag{1}$$

$$H^- + He \rightarrow H^0 + He + e, \tag{2}$$

$$H^0 + He \rightarrow H^+ + He + e \tag{3}$$

The cross-sections of these reactions at the ion energy 14 keV are [7]: $\sigma_1 = 5\,10^{-17}\ cm^2, \sigma_2 = 5\,10^{-16}\ cm^2, \sigma_3 = 1.5\,10^{-16}\ cm^2$.

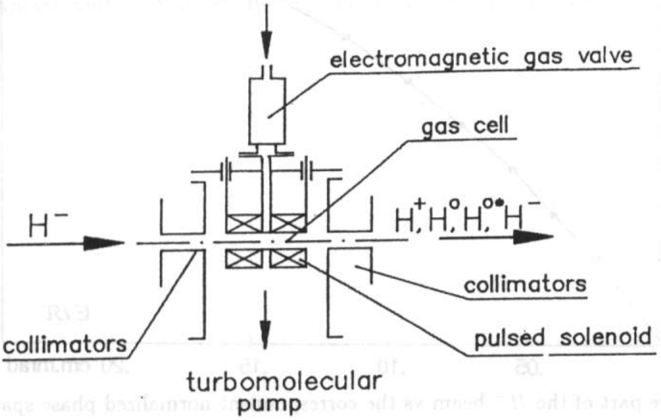

Fig. 3. Schematic diagram of the gaseous stripping target.

There is not proton depolarization during the first process because both electrons are lost in a short time $\sim 10^{-16}$ s which is much less than the period of proton spin precession in characteristic atomic magnetic field. Partial proton depolarization arises in second two-step process due to spin-spin interaction in neutral hydrogen atom after single electron loss by H^- ion. The depolarization can be eliminated by applying strong ($\gg 507$ G) magnetic field to the gaseous target.

For the target thickness $\sim 10^{14}$ cm^{-2} one-step process is clearly dominant. For such a thin target the proton depolarization is negligible and magnetic field in the target is not necessary. For this mode of the polarimeter operation only small part of H^-

ions ($\leq 0.5\%$) is converted into protons. For the target thickness $\sim 10^{16} cm^{-2}$ about half of H^- ions can be converted into H^+, but strong magnetic field have to be applied to the target in order to prevent protons depolarization.
Polarization measurements made in the course of this work have been performed by using thin helium stripping target with the target thickness about $10^{14} cm^{-2}$.

4 Results

Pulsed polarized H^- ion beam with peak current up to 600 μA has been extracted from the source described. Pulse duration of the beam is $200 \mu s$, repetition rate $5\, Hz$. Corresponding D^- ion current is $5\ mA$. D^- beam space charge becomes essential at this intensity for a transport of D^- through the deflecting magnet. Gaseous space charge neutralization was employed for measurement of the D^- ion current.
For typical conditions polarization of H^- beam has been measured to be 0.88 ± 0.01 (one standard statistical error is given).

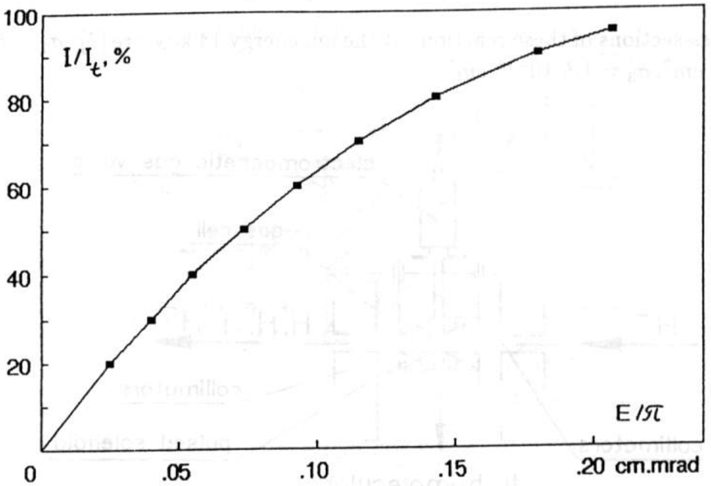

Fig. 4. Relative part of the H^- beam vs the correspondent normalized phase space area.

Results of emittance measurements are shown in Fig.4. The normalized emittance of the H^- beam (for 90% of beam particles) is equal to $1.8\ \pi\ mm\ mrad$.

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POLARIZED ELECTRONS AT NIKHEF

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A design for producing a beam of longitudinally polarized electrons stored in the AmPS ring has been made by a collaboration between NIKHEF, the Budker Institute for Nuclear Physics (BINP) and the Institute of Semiconductor Physics (ISP) from Novosibirsk. The polarized electrons are produced by illuminating a photoemissive cathode with circularly polarized light. A 100 keV electron beam with a peak current up to 40 mA and a pulse length up to 4 μs is extracted from the cathode at a maximum repetition rate of 2 Hz.

1 Introduction

At the *Amsterdam Pulse Stretcher and Storage* (AmPS) [1] ring the time required for radiative polarization is much larger than the beam lifetime, so that polarized electrons have to be injected. A design for producing a stored beam of longitudinally polarized electrons has been made by a collaboration between NIKHEF, the Budker Institute for Nuclear Physics (BINP) and the Institute of Semiconductor Physics (ISP) from Novosibirsk. In this design the most recent insights in the field and the necessary requirements for coupling of the polarized source to the existing injection system of the accelerator have been incorporated.

In fig. 1 the injection area of the NIKHEF facility is shown with the existing thermionic gun and the polarized source. Polarized electrons are produced by illuminating a photoemissive cathode with circularly polarized light. A Z-shape spin manipulation system rotates the polarization vector over any

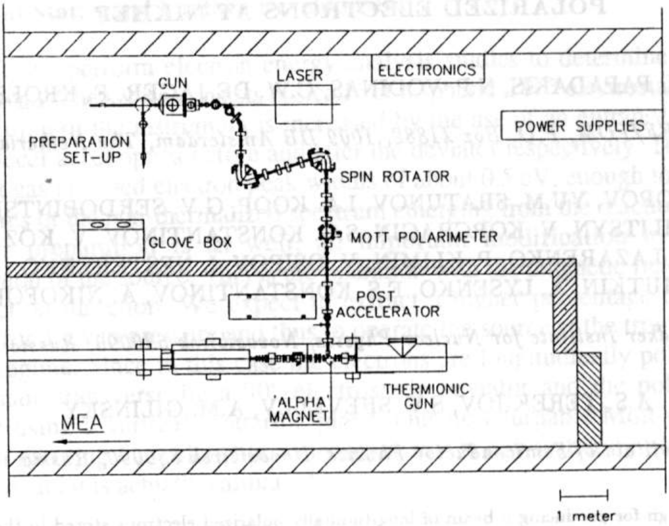

Figure 1: The NIKHEF injector area with the unpolarized and polarized electron sources.

arbitrary angle. The degree of polarization is measured with a Mott polarimeter. A post-accelerator increases the energy of the electrons to 400 keV required before the electron beam can be injected into the MEA linac (the linear accelerator of NIKHEF). In storage rings the spin precesses relative to the electron momentum. In order to maintain the polarization longitudinal at the interaction point, a *Siberian Snake* will be installed in the East straight section of the AmPS ring, opposite to the interaction point. The polarization degree in the ring is measured by a Compton laser backscattering polarimeter [2].

2 The AmPS polarized electron beam

Our photocathode gun has been designed to deliver a variably pulsed (0.7-4μs) polarized electron beam of 100 keV kinetic energy. The extracted peak current can be as high as 40 mA at a repetition rate 2 Hz. The polarized electron injector consists of the following main parts: the preparation set-up, the photocathode gun, the laser and the optical circuit, the Z-shape spin manipulator, the Mott polarimeter and the post-accelerator (Figure 1).

In our design the preparation of the photocathode to Negative Electron Affinity (NEA) state is performed in a preparation set-up, permanently connected at the rear side of the photocathode gun and isolated from it by a UHV valve. Lifetime and quantum efficiency measurements can also be performed. This procedure can be done while the gun is in operation. The photocathodes are transferred from the preparation set-up to the gun chamber with a magnetically driven manipulator under UHV environment. This design has three major advantanges. It makes the preparation procedure of the photocathodes

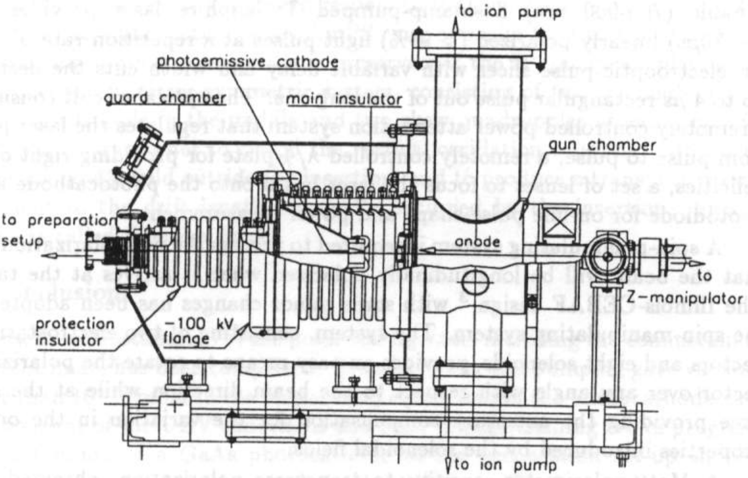

Figure 2: The mechanical design of the NIKHEF's photocathode gun.

more efficient, it preserves the UHV conditions in the photocathode gun and it gives the ability to activate photocathodes while the photocathode gun is in operation.

The photocathode gun can be divided into the following sections starting from the back: the protection insulator, the main insulator and the gun chamber. A large guard chamber covers both insulators (Figure 2).

The main insulator is made of 9 ceramic rings sandwiched between 10 rings of conducting material. A voltage divider decreases gradually the high voltage from -100 kV at the flange connecting the protection insulator to the main insulator, to zero at the anode flange. In this way adjacent rings are held approximately to one tenth of the maximum voltage minimizing the possibility of sparking, which could result a damage of the insulator. A set of 8 screens protects the inside of the insulating material from direct electron hit. The cathode position is at the end of a stainless steel cone.

The protection insulator is installed between the connection tube to the preparation set-up and the main insulator. It has the same design as the main insulator. The gun chamber is located immediately after the anode flange. It has a cylindrical shape and supports the ports where the ion pumps, the vacuum gauges and the mass spectrometer are connected. A large guard chamber covers the protection and the main insulators. It is held to vacuum of the order of 10^{-6} mbar protecting the insulators to come in contact with the ambient atmosphere. It supports and isolates the high voltage connection from the surrounding environment.

A laser and an optical circuit provide the circularly polarized light. A tunable (700-900 nm) flashlamp-pumped Ti:Sapphire laser provides long ($\sim 30\mu s$) linearly polarized ($> 99\%$) light pulses at a repetition rate of 2 Hz. An electrooptic pulse slicer with variable delay and width cuts the desirable up to 4 μs rectangular pulse out of the long one. The optical circuit consists of a remotely controlled power attenuation system that regulates the laser power from pulse to pulse, a remotely controlled $\lambda/4$-plate for providing right or left helicities, a set of lenses to focus the laser beam onto the photocathode and a photodiode for on-line pulse-shape and power measurements.

A spin-manipulating system is required to precess the net polarization such that the beam will be longitudinally polarized when it arrives at the target. The Illinois-CEBAF design [3] with some minor changes has been adopted for the spin-manipulating system. The system, consisting of two electrostatic deflectors and eight solenoids, provides an easy means to rotate the polarization vector over any angle with respect to the beam direction while at the same time providing the necessary compensation for the variation in the optical properties introduced by the solenoidal fields.

A Mott polarimeter sensitive to transverse polarization, obtained with the spin manipulator, measures the polarization degree. Thin gold foils are used as scattering targets. Two silicon detectors, symmetrically mounted with respect to beam momentum, measure the expected asymmetry while two other identical detectors monitor instrumental asymmetries.

The post-accelerator consists of two cavities, one for bunching and the other for accelerating the electron beam to 400 keV. The acceleration of the electron beam is necessary because the existing thermionic gun delivers a 400 keV unpolarized electron beam. An 'alpha'-magnet deflects the polarized electron beam over 270^0 without dispersion into the MEA linac. A valve, installed between the post-accelerator and the 'alpha'-magnet, offers a complete isolation of the whole system from MEA linac. With this scheme either a polarized or an unpolarized electron beam can be injected.

A set of beam diagnostics consisting of two beam current monitors, several TV screens and a multiwire scanner has been designed for monitoring the electron beam throughout the system.

The post-accelerator capture efficiency of 20% results in an 8 mA peak current electron beam injected into the MEA linac. By three-turn injection 20 mA is then captured in the AmPS ring. Consecutive pulses accelerated in MEA are stacked into the ring until an intensity of over 100 mA is reached. A beam with energy up to 700 MeV can be injected directly into the ring. The stored beam can also be ramped up till a maximum energy of 900 MeV.

In storage rings the spin precesses relative to the electron momentum, and no longer be longitudinal at the interaction point (IP). If a device, which rotates the spin over an angle with respect to the beam momentum is inserted in the East straight section of the AmPS ring, opposite to that where the IP is located, longitudinal polarization is preserved at the IP, independently of the beam energy. A mirror-symmetric system, consisting of two solenoids with a normal quadrupole in the middle and two skew quadrupoles at each end, has been optimized in order to cancel the vertical oscillation coupling, introduced by the solenoidal field outside the insertion, and to produce a transport matrix equivalent to the drift length physically occupied by the insertion. Such a scheme is called *Siberian Snake*.

3 Conclusions

At present the installation of the polarized injector, including the connection to the MEA linac, has been completed. First bake-out and pumping gave vacuum better than 10^{-10} mbar in the preparation set-up and in the photocathode gun. Improvement of the UHV conditions and high voltage training are in progress. First activation of a GaAs photocathode in the preparation set-up showed a lifetime of the order of several hundred hours. The same photocathode placed in the gun chamber, illuminated by a HeNe laser showed lifetime of approximately 80 hours and maximum polarization of 20%. These results show that UHV conditions in the preparation set-up have already been established. The Z-manipulator has been successfully tested. The new Ti:Sapphire laser has recently been installed and first measurements begun.

The *Siberian Snake* will be installed in the ring during the Summer 95 shutdown period of the accelerator. The commissioning of all parts will be performed during the Autumn of 1995 and first polarized beam in the AmPS ring is expected before the end of 1995.

Acknowledgments

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BEAM-TARGET INTERACTIONS AT AmPS

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Specific design aspects of the storage cell in internal-target electron-scattering experiments, such as beam lifetimes, impact on ring vacuum, beam halo studies and detector backgrounds, are discussed. Experience on such issues gained during the 91-12 experiment at NIKHEF is presented and will serve as a guideline for future experiments and future targets.

1 Introduction

A strong internal-target physics program at the 900 MeV 100% duty factor AmPS electron storage ring of NIKHEF-K is presently being pursued. The storage cell technique has proven to be extremely useful for experiments with polarized targets and/or polarized beams. Recently, target thicknesses[1] of 2×10^{13} At cm^{-2} at a flow of 2×10^{16} At s^{-1} tensor polarized deuterium atoms have been successfully reached into a 15 mm diameter, 40 cm long storage cell without running into major obstacles on the machine side. We presently find that the ring vacuum is the major factor limiting the experimentally observed lifetime, while backgrounds induced by the 25 μm cell walls are kept at a tolerable level. This indicates that a further reduction of the cell aperture might be possible. Still, it is necessary to gain an understanding of the limitations which might occur for future denser targets and of different nuclear species (e.g. ^4He and polarized $^3\vec{H}e^2$).

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2 Beam lifetime during the experiment

In a storage ring particles interacting with the residual gas in the vacuum line or with the target materials, may leak out of the machine stable phase space because of scattering beyond the ring geometrical or energy acceptance. The insertion of a storage tube as a target amplifies these effects, as the beam is forced to be recirculated through a region of high gas density and very limited aperture. Under the assumption that particle loss in the target region and elsewhere in the ring are statistically independent, the total lifetime τ can be written as:

$$\frac{1}{\tau} = \frac{1}{\tau_0} + \frac{1}{\tau_{gas}} \tag{1}$$

with an intrinsic contribution coming from the ring and another one from the target gas itself. While τ_{gas} is a direct consequence of the density chosen, one would like to keep the ring intrinsic storage time τ_0 as large as possible in order not to play an important role in eq. 1. In fig. 1 the measured τ_{gas} at 565 MeV is

Figure 1: The inverse of the intrinsic gas lifetime for H_2 and N_2 as a function of equivalent target densities at 565 MeV and 40 mA circulating current

shown for H_2 and N_2. The lifetime scales inversely proportional to the target thickness in the cell. Furthermore in going from one gas species to another, it scales almost exactly with the bremsstrahlung cross section, i.e. with a

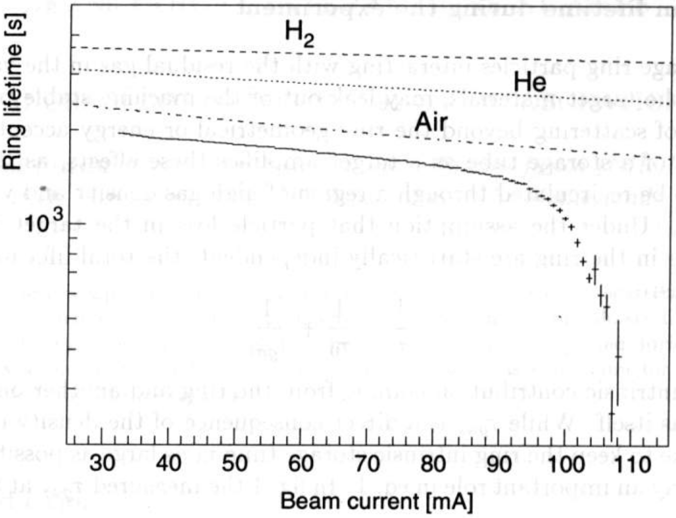

Figure 2: The ring intrinsic lifetime as a function of current. The crosses are the measured data, the broken curves extrapolations for different vacuum compositions. The effect of CO_2 is very similar to that of air

factor $Z(Z+1)$, whereas for elastic single or multiple scattering the scaling would have been proportional to the atomic charge Z only. This indicates that the radiative energy loss of particles in the target is dominant in this energy region, although it is true that given the lower than predicted values of τ_{gas}, bremsstrahlung might have been excessively weighted by imperfections in the RF system of the ring.

A rather puzzling behaviour was observed for τ_0. In fig. 2 the ring instantaneous lifetime is shown: there is a clear decreasing trend towards higher beam currents, which collapses in a beam blow up above 100 mA. The gradual decrease in lifetime in the low current region is correlated to an increase of the ring residual pressure which was observed only in the curved sections and was independent of gas flow in the internal target area. Therefore this effect can be attributed to synchrotron radiation induced gas desorption from the pipe walls.

It has to be noted that an average pressure of few $\times 10^{-8}$ mbar over the 212 m ring circumference, corresponds to a total thickness of $\approx 10^{13}$ At cm^{-2} of, in principle, unknown atomic species with probably a high contamination of high Z materials (e.g. CO, CO_2), therefore contributing non-negligibly to the lifetime during data taking on polarized deuterium. Also in fig. 2, extrapolated lifetimes from theoretical expectations taking into account this effective target thickness along the ring, are shown for different residual gas compositions.

A possible explanation for the missing strength could be ion trapping in the beam potential of ionized residual atoms or molecules. This could create a pressure gradient in the beam pipe, such that the actual gas density at the beam spot was larger than the one measured, thus explaining the smaller lifetime. In order to compensate for such an effect, ion-clearing electrodes were installed at various ring positions and operated at a maximum voltage of 3.5 kV.

This could have been insufficient at the highest current, as at 100 mA and for a beam core of a few mm the electrical field created by the circulating current could be larger than the constant field gradient produced by the electrodes: consequently the ion-clearing mechanism was not guaranteed and the rapid beam neutralization made possible. Other major effects associated with ion trapping are the possible introduction of incoherent tune shifts, emittance growth and resonance (wake fields) excitations[3].

3 Slits studies

The density in a storage cell is proportional to the inverse cube of its diameter. Therefore one should aim at reducing this aperture to the minimal tolerable value, whilst not affecting the beam lifetime and keeping detector background at an acceptable level.

Very little is known about spatial distributions of stored electron beams: it is expected that after damping (which occurs within a second at these energies) the beam profile should follow a gaussian shape with a σ-value of the order of 1 mm. Scattering with residual gas and wake fields excitations, however, will start populating the tails of the distribution thus creating a non-gaussian beam halo, which extends down to about $8-10\,\sigma$. It is the interaction of particles in this halo with the target cell walls which is responsible for background events not coming from the target gas.

In order to obtain information on the beam in the presence of a very small aperture, lifetime data have been taken while placing 4 movable 1 cm thick tungsten slits at known positions inside the beam pipe. The slits could be positioned as close as 1.4 mm to each other. Data for such measurements are shown in fig. 3. Intersecting the beam with a movable collimator should not affect the lifetime until the actual beam core is reached. Then the effect of such a restricted aperture should become dominant in determining τ_0 which will therefore become inversely proportional to the aperture squared[4]. Indeed one observes once more[5] that the beam lifetime starts being affected by the

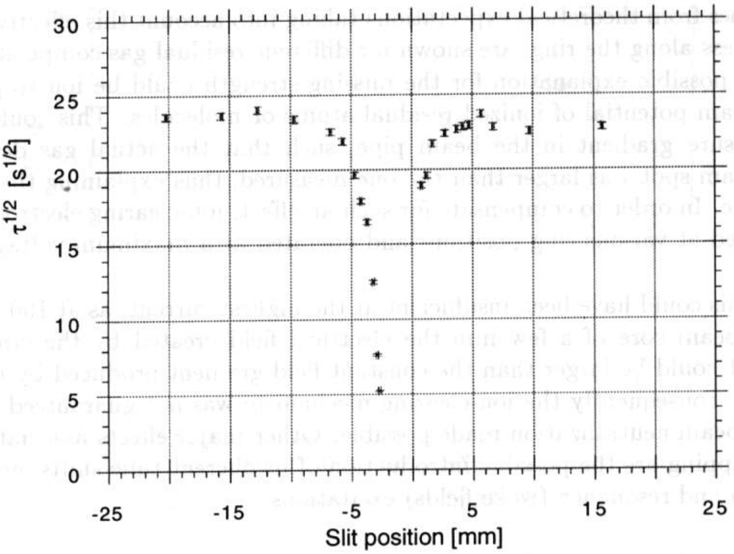

Figure 3: Measured values of $\tau^{1/2}$ when moving two slits in the machine plane.

collimators only at very inner positions, while the single rates produced by the beam halo are rapidly growing much earlier. Therefore, very aggressive cell diameters like 10 – 12 mm could be chosen, provided one can still operate the detector system. As the beam dimension out of the machine plane is expected to be much smaller than the one in plane, one could also, in the absence of intra-beam $x - y$ coupling, consider elliptically shaped cells. The slits system itself, when placed in a far away section of the ring, is extremely helpful in cutting away part of the beam halo at every turn and is one of the experimental parameters by which one can tune or minimize the wall events background.

The cell diameter ultimately depends also on the type of detector and what particles one is looking for. Indeed heavy recoil detection (A=4 or A=3) poses less stringent limits, as a trigger for a helium isotope is not likely to originate from a wall event. At present, for a 15 mm diameter cell with tensor-polarized deuterium we find a raw wall events rate of ≈ 700 Hz/mA , which by imposing conditions on the event reconstruction and vertex, drops to a fraction of nearly 30% of the total data and can be monitored by taking data on an empty storage cell[6]. Of course by having a more powerful target source available, this ratio will drop down to a negligible fraction, for the same cell diameter.

4 Conclusions

We are presently able to successfully operate a 15 mm diameter, 40 cm long storage-cell target within the ring vacuum environment. Backgrounds are manageable and a good fraction of them is removed during off-line analysis provided track reconstruction with a sufficient resolution is possible. In the future, the cell diameter might even be decreased and a parallel improvement program for β-function and emittance reduction is underway[7]. As for denser targets the intrinsic gas lifetime contribution is expected to be considerably smaller (of the order of 80 s at 10^{16} He-At cm^{-2}), improvements are planned for the ring vacuum. More pumping capacity through NEG strips will be added and a systematic investigation of clearing mechanisms will be pursued. Also, the impact of the gas flow on the ring vacuum will be minimized by larger pumping speeds in the target region.

Aknowledgements

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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 workshop[1]. 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 deuterium[2]. Tensor-polarized deuterons are produced in

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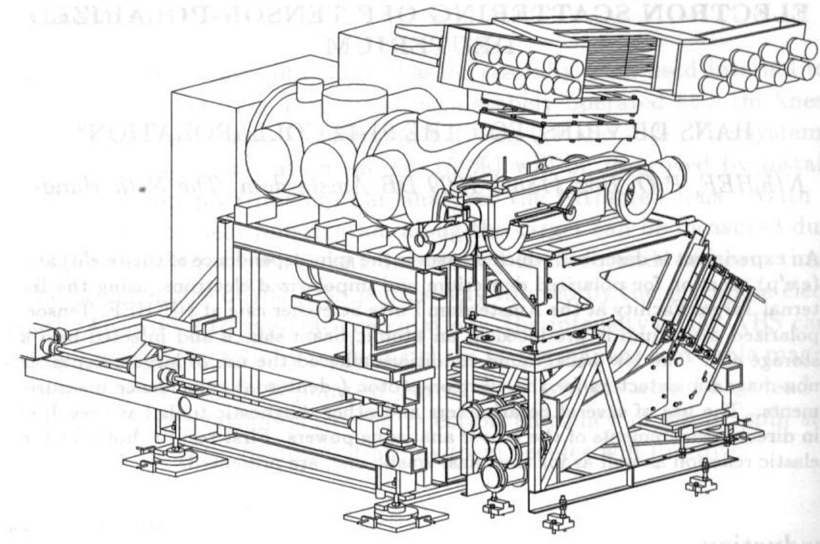

Figure 1: Overview of the NIKHEF internal target set-up, showing the target cell (central part of the figure), the Atomic Beam Source (at the left), the Range Telescope (upper detector) and the Calorimeter (lower detector)

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

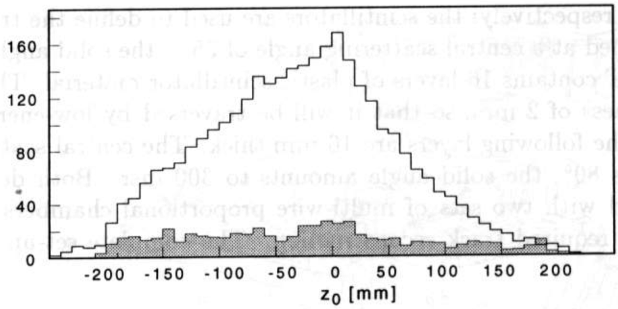

Figure 2: Reconstructed vertex position along the target cell. The shaded area indicates the background measured with an empty target cell.

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 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 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^{16}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.

Detector part	Countrate	
	background	gas
Range Telescope layer 1	744	143
Range Telescope layer 2	130	18
Calorimeter scint. 1	536	106
Calorimeter scint. 2	32	2.4
Calorimeter arm triggers	3.2	0.3
Wire Chamber CM vertex	900	172
Wire Chamber Range Telescope	470	88

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 ^{1}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. 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

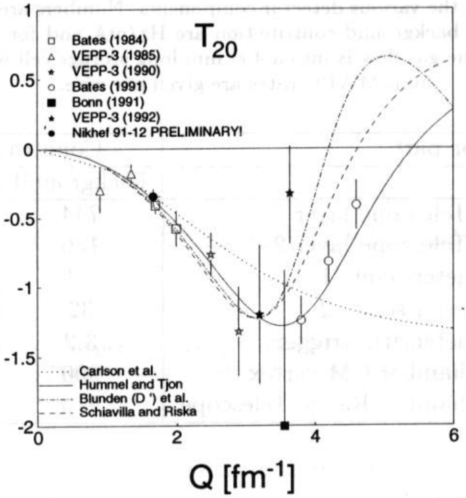

Figure 3: Experimental results and theoretical predictions for the tensor analyzing power T_{20}.

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±7% [4].

The consistency of the polarization measurements is confirmed by the first results of the analysis. Electrons scattered elastically through 30 ° in the CM were detected in coincidence with the recoiling deuterons at 65 °. 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[6] 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[7].

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.

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