EE

Spin-exchange Polarization Study at the TRIUMF OPPIS

A.N. Zelenski*, C.D.P. Levy, W.T.H. van Oers, P.W. Schmor,
J. Welz, G.W. Wight

TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. Canada V6T 2A9

Abstract. The TRIUMF optically pumped polarized ion source (OPPIS) now produces 56 μA H^- ion current and 85% polarization for routine operation and 120 μA and 78% polarization in high current mode. This is a result of the latest ECR primary proton source improvements and optimization of optical pumping efficiency. It has been shown that in a pulsed mode suitable for high energy accelerator applications, it is possible to produce 1 - 2 mA of polarized H^- current in a charge-exchange OPPIS based on the INR-scheme(1). A possible INR-scheme upgrade to the 10 mA range is discussed. The experimental results on spin-exchange polarization presented in this paper hold promise of polarized H^- current increasing to the 10 mA range.

INTRODUCTION

Understanding is growing of the importance of polarization experiments with fixed targets or colliding beams in the TeV energy range(2,3). The development of polarization facilities for 500 GeV pp collisions at RHIC has succeeded recently with the partial "siberian snake" application for polarization preservation in the AGS synchrotron. The studies undertaken by the SPIN collaboration have shown the feasibility of polarized beam acceleration in the FNAL Main injector and Tevatron-Collider(4). An essential experimental facility is a high current source of polarized H^- ions. A pulsed current of 1.2 mA is required to produce a polarized proton-antiproton collision luminosity of about $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, equal to the projected unpolarized value at FNAL(4). The development of such a source is vital to the future polarization program, because of competition with experiments using unpolarized beam. Ideally, the polarized ion source should deliver polarized H^- current similar to unpolarized beam (i.e. in excess of 10 mA). Here will be examined limitations on maximum current in different types of polarized ion source

*Visitor from Institute for Nuclear Research, Moscow, Russia

SCAN-9412093

CERN LIBRARIES, GENEVA

SW 94 50

and then the latest results of the spin-exchange polarization technique development will be presented, which promises that a pulsed, optically-pumped polarized ion source will meet the above requirements. It is instructive to consider the two competing techniques - the atomic beam source (ABS) and the optically-pumped polarized ion source - in the same way, since they have many common features. The general polarization scheme is basically the same. In the first step, electron-spin polarized atoms are produced; in the second, electron polarization is transferred to nuclei by means of hyperfine interactions, and in the last step atoms are ionized. The difference is the energy of the atomic H beam.

a) Polarization of a low energy beam (temperatures below a few hundred K). In the ABS a separated sextupole magnet selects hydrogen atoms in one particular spin state. The acceptance of separated magnets is limited by the maximum sextupole field and minimum beam velocity. Intrabeam scattering limits the usefulness of any temperature decrease below 30 K. It appears that parameters have been well-optimized and 10^{17} atoms/sec in a ionizer acceptance cannot be substantially improved. The most optimistic extrapolation based on the use of a superconducting sextupole gives only a factor of 3 increase of atomic flux.

Scattering is an inevitable limit only for the conventional ABS technique with the separating magnet. There is a possibility of H polarization in spin-exchange collisions with optically-pumped alkali-metal vapour in a cell. A polarized atomic H flux in excess of 10^{18} sec^{-1} has been obtained by the use of K-H spin-exchange collisions. With a proper choice of cell wall material and temperature regime, recombination can be reduced to 20-30%. Selective ionization of atomic hydrogen must be used to preserve polarization. Ionizers using a Cs beam or a D-enriched plasma are selective but the presently obtained ionization efficiency is quite low (0.3-0.5%). Nonetheless, with a 10^{18} sec^{-1} atomic H flux up to 1.0 mA polarized H^- current would perhaps be produced.

b) Polarization of a fast 0.5 - 5.0 keV beam. An advantage of the fast atomic H beam is the ease of conversion to a negative H^- ion beam. In the sodium ionizer cell the equilibrium yield is about 9% at 1 - 5 keV beam energies. At 0.5 - 1.0 keV energies the yield is 16% in a Rb ionizer cell. The electron polarization of a fast H beam can be obtained either in a charge-exchange process, in which primary protons capture polarized electrons from optically-pumped alkali-metal vapour, or in spin-exchange collisions. All present operational OPPIS's are based on charge-exchange polarization. The currents from OPPIS using ECR primary proton sources are limited by the ECR

plasma temperature and emittance degradation, which is introduced by the beam extraction system operating in a high magnetic field.

In the INR OPPIS this limitation has been overcome by using a high-brightness atomic H beam injector which is situated outside the magnetic field(5). In this injector the high density plasma is initially expanded in vacuum and efficiently cooled down to 0.2 eV. A four-grid extraction system is used for extraction of a low divergence beam with up to 0.4 A/cm² current density. The proton beam is focussed by a solenoidal magnetic lens and then neutralized in a pulsed H₂ gas cell. As a result an atomic H beam intensity up to 3×10^{18} atoms/sec within the ionizer acceptance was obtained(6). This is a 30 times higher flux than for the best ABS. In the INR OPPIS the atomic H beam is injected into a high magnetic field solenoid where it is ionized in a pulsed He gas cell. In effect the He ionizer cell serves as a proton source in a high magnetic field, like the ECR source, but with higher current density and much less beam divergence. The Novosibirsk source is capable of producing a few hundred mA of equivalent atomic H beam within the ionizer acceptance, which would allow a few tens of mA of polarized H⁺ beam to be obtained(6). However, it is expected that space-charge of the proton beam and the Rb ions produced in the charge-exchange polarization process will increase the beam divergence and reduce the current at some point.

In the INR scheme both injected and outgoing beams are neutral so space-charge is compensated. The equilibrium fraction of neutral H beam after the He ionizer is 20% and without separation the unpolarized atoms will reduce the final proton polarization. A bias voltage applied to the He ionizer gives the polarized and unpolarized beam energy separation but destroys space-charge compensation. It is possible to reduce the fraction of unpolarized atoms produced in H⁺ - He collisions by using a mixture of He and optically-pumped Rb vapour in the same 100 cm-long cell. The Rb vapour density must be near the radiation trapping limit of 10^{13} atoms/cm³ and the He density about 2×10^{14} atoms/cm³. In this case the full He thickness will be enough to provide a high ionization efficiency but neutralization will mainly be due to polarized electron pick-up from Rb atoms, since the average neutralization length on Rb: $(\sigma_{+0}N)_{Rb}^{-1}$ is 12 cm and on He: $(\sigma_{+0}N)_{He}^{-1}$ is 200 cm. Simultaneously He - Rb buffering collisions will increase the Rb polarization relaxation time, and spin-exchange collisions in a thick 10^{15} atoms/cm² Rb cell will further help increase polarization. We believe that this scheme will avoid space-charge current limitations and will probably compete with the spin-exchange technique in the 10 mA polarized H⁺ current range.

EXPERIMENTAL STUDIES OF SPIN-EXCHANGE POLARIZATION

The experiments were done at the operational TRIUMF OPPIS setup, which was modified in the following way (see Fig. 1). A duoplasmatron followed by a Rb neutralizing cell was used as an injector of atomic H beam. The OPPIS ECR source was removed and the magnetic field in the solenoid was adjusted to a flat shape. A longer 60 cm optically-pumped Rb cell was installed (inner liner diameter 12 mm). The Sona transition, ionizer and polarization diagnostics were exactly the same as for the well-studied charge-exchange OPPIS, so that all polarization measurements could be compared with well-known reference points.

The proton polarization was measured at 300 keV in a polarimeter based on the $\bar{p}(^6\text{Li}, ^3\text{He})^4\text{He}$ reaction. This polarimeter was calibrated by comparison with the reference 200 MeV polarimeters. In all experiments fast spin-reversal was used with a 40 Hz repetition rate and a synchronous detection technique for noise reduction. As a result, the proton polarization measurement accuracy of about $\pm 1.5\%$ was routinely obtained in a 5-minute integration time. For Rb thickness and polarization measurements the well-developed technique of Faraday rotation was used.

The results of the H⁺ polarization measurements are presented in Fig. 2. The polarization grows quickly with Rb thickness up to a thickness of 3×10^{14} atoms/cm². A wide plateau is the result of competition between spin-exchange

Figure 1. Setup for spin-exchange polarization measurements. 1) Lyman-alpha polarimeter, 2) ionizer Rb cell, 3) Sona transition region, 4) 10 kG S.C. solenoid magnet, 5) 60 cm optically-pumped Rb cell, 6) neutralizer Rb cell, 7) duoplasmatron, 8) window for probe laser, 9) turbopump, 10-11) deflection plates, 12) cryopump, 13) pump laser light.

collisions, which push polarization up, and radiation trapping, which pulls Rb and hence proton polarization down. The maximum thickness of highly polarized Rb is limited by available laser power in the dc mode of operation. Nonetheless, the maximum 48% H^- polarization is very satisfactory for a dc source without any dryfilm coating. In the pulsed mode suitable for high energy accelerators the density and thickness could be at least doubled by using high power pulsed lasers. The proton polarization would then increase to 80% (see Ref. (7)).

The energy dependence of spin-exchange cross sections has been studied in the range of 0.5 – 2.0 keV (see Fig. 3). The cross sections are close to calculated values but a substantial shift in the position of the maximum was

Figure 2. Rb and H^- polarization dependence on Rb thickness, using an uncoated 60 cm long cell.

Figure 3. H-Rb spin-exchange cross section dependence on atomic H beam energy. Data points, present work; solid line, calculated value.(8)

observed. A polarized H^- current of about $10 \mu A$ was obtained with a duoplasmatron from the old TRIUMF Lamb-shift source without any special optimization. It is planned to develop a high brightness atomic hydrogen injector in collaboration with BINP Novosibirsk to replace the duoplasmatron. With a new atomic beam injector one expects the polarized H^- ion current to be in the 10 mA range(9).

CONCLUSIONS

Recent development of polarized ion sources and polarization preservation techniques make feasible high energy polarized beam facilities. The use of the optical pumping technique has remarkably improved the polarized target and polarized ion source parameters. At present the TRIUMF dc OPPIS produces polarized H^- current of $120 \mu A$. The pulsed INR-type OPPIS could produce at least 1 mA H^- current; therefore the TRIUMF-INR-KEK-BINP team has proposed source development in the frame work of the SPIN collaboration for experiments at FNAL. The results of the present work are very promising for the future development of a 10 mA pulsed spin-exchange OPPIS.

ACKNOWLEDGEMENTS

We would like to thank G. Dutto, D. Swenson, Y. Mori and D. Tupa for helpful discussions. We wish to acknowledge the help of the engineering and technical staff of the Ion Source Injector group for assistance in OPPIS development and especially the contributions of M. McDonald and R. Ruegg. We would like to thank A.D. Krisch for his encouragement and support of high-current OPPIS development.

REFERENCES

1. Zelenski, A.N., *et al.*, AIP Conf. Proc. No. 293, 175, (1994).
2. Bourelly, C., *et al.*, Phys. Rep. **177**, 319, (1989).
3. Taxil, P., Proc. 10th Intern. Symp. on High Energy Spin Physics, Universal Academy Press, Inc., Tokyo, Japan, 215, (1992).
4. 1994 SPIN progress report, Univ. of Michigan, spokesman A.D. Krisch.
5. Zelenski, A.N., *et al.*, Nucl. Instrum. Methods, **A245**, 223, (1986).
6. Belchenko, Ya. I., *et al.*, Rev. Sci. Instrum. **61**, 378 (1990).
7. Zelenski, A.N., *et al.*, "Development of a spin-exchange polarized H^- ion source for high energy accelerators", presented at the European Particle Accelerator Conference, London, UK, June 27–July 1, 1994.
8. Swenson, D.R., *et al.*, J. Phys. B., **18**, 4433 (1985).
9. Zelenski, A.N., Kochanovski, S.A., AIP Conf. Proc., No. 293, 164, (1994).