Proceedings of the 13th International Conference on Cyclotrons and their Applications, Vancouver, BC, Canada

STATUS OF THE TRIUMF OPTICALLY-PUMPED POLARIZED H⁻ ION SOURCE

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ABSTRACT

The TRIUMF polarized H^- ion source, based on optical pumping of Rb vapour, produces up to 10 μA of 75% polarized H^- beam at 300 keV. A 1–10 keV polarimeter, based on the detection of Lyman-α photons from metastable H(2S) atoms, has been used to study source parameters affecting polarization, which is up to 80% at low current. Preliminary measurements of beam intensity variations correlated with the Rb polarization show that they are likely within the requirements of an upcoming parity violation experiment.

1. INTRODUCTION

The optically pumped polarized ion source (OPPIS) at TRIUMF has been described previously.[1,2] It now produces up to 10 μA of 75% polarized H^- beam at 300 keV, half of which is accelerated to high energy by the TRIUMF cyclotron. Figure 1 is a schematic drawing of OPPIS. Figure 2 shows the downstream section of OPPIS, containing beam transport optics and a low-energy (1–10 keV) polarimeter. Bender plates divert polarized protons produced (with about 10% of the polarized H^- intensity) by the source into the polarimeter, where they are neutralized in a Na cell. Electron-spin-down H(2S) metastables are quenched in a spin filter (as in the Lamb-shift source), and Lyman-α photons emitted by the remaining metastables after quenching in an electric field are counted. The proton polarization is calculated from the asymmetry in photon counts between the polarized (lasers on) and unpolarized (lasers off) cases.[3] Count rates are of the order of 500,000/s.

Many factors affect the polarization, and only small improvements are possible from each, given that the polarization is already quite high. The Lyman-α polarimeter has allowed us to measure small changes in the polarization and to begin a program of further improvement in polarization.

Our other interest is the application of the source to parity violation experiments. The measurement of the parity violation amplitude in pp scattering requires

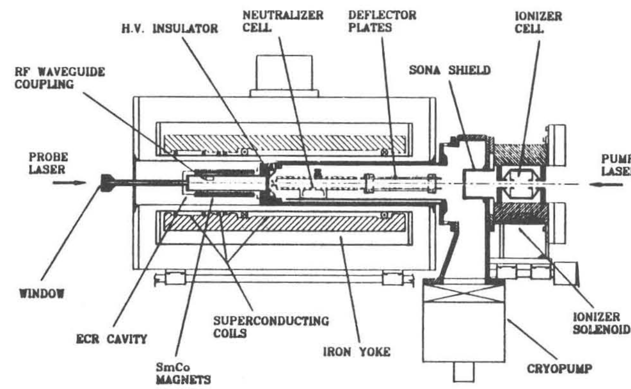

Fig. 1. Schematic diagram of the TRIUMF optically-pumped polarized H^- ion source.

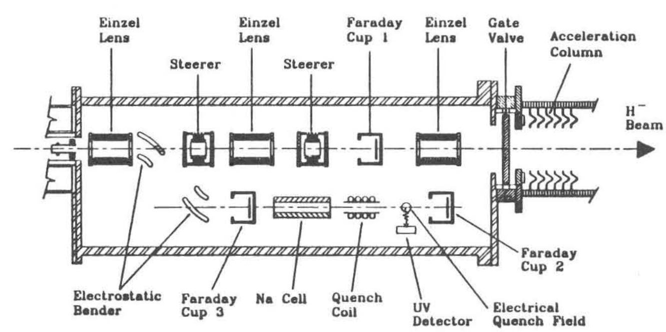

Fig. 2. Schematic diagram of the beam transport optics downstream of the ion source, and the Lyman-α polarimeter contained within the same chamber. During normal source operation the H^- beam passes through a 2.0 cm diameter aperture in the first electrostatic bender. During polarimeter operation deflecting voltages are applied to the benders. Faraday Cups 1 and 3 can be moved out of the beam axis. The UV detector is a dual microchannel plate protected by a LiF window.

extremely high beam stability, especially with respect to current modulation (CM) correlated with spin helicity. Spin reversal is achieved by reversing the circular polarization of the pump laser light and adjusting the laser frequency to allow for the Zeeman shift of $\sim$ 85 GHz in the Rb neutralizer target, which is immersed in a high magnetic field of $\sim$ 23 kG. At least two properties of optical pumping of alkali vapour are known that affect the polarized ion current. The best understood is the dependence of the neutral beam emitted by the Rb cell on the Rb polarization.[4] Some neutrals undergo a second charge exchange reaction in the Rb to become H^-. Since H^- has a single bound state ${}^1S_0$, it cannot be formed by a polarized hydrogen atom picking up an electron from Rb polarized in the same direction. The H^- yield in the Rb is given by

$$I_- \sim I_0 \sigma_{o-} nl(1 - TP^2)C \qquad (1)$$

where I_0 is the H^0 yield in the Rb, $\sigma_{o-} \sim 3 \times 10^{-16}$ cm^2 is the cross section for H^- production, $nl \sim 5 \times 10^{13}$ atoms cm^{-2} is the Rb thickness, P is the Rb polarization, $T \sim 1$ is the polarization tranfer ratio between Rb and H^0, and $C \sim 0.5$ is a correction factor accounting for integration of H^- production along the length of the cell. All the I_- is swept out of the beam by deflection plates between the Rb cell and the Na negative ionizer cell (see Fig. 1), giving rise to a dependence of the ultimate polarized H^- source current on P. For Rb polarizations P_{up} and P_{down}, and ultimate H^- currents I_{up}, I_{down}, and $I_{\text{unpolarized}}$, the following is true:

$$\frac{I_{\text{up}} - I_{\text{down}}}{I_{\text{unpolarized}}} \sim \sigma_{o-} nl\{P^2_{\text{up}} - P^2_{\text{down}}\}TC \qquad (2)$$

For useful parity violation measurements, the asymmetry in polarized current is required to be of the order of 10^{-5}. The above equation implies that the upper limit on Rb polarization asymmetry is about 10^{-3}, thus requiring a thin Rb target with highly saturated polarization.

A second physical process producing CM is the ionization of Rb vapour by resonant D1 line laser light. CM due to this effect was first seen at INR, Moscow.[5] A reduction in current of close to 100% was observed when the Na density was more than 10^{13} atoms cm^{-3} and high pulsed laser power was used. The ionization is caused by a process involving collisions between excited state atoms, and is highly non-linear with respect to both laser power and vapour density. Direct measurements of alkali ion production under the action of resonant light were first carried out in 1983.[6] Since the ionization process decreases the vapour density and hence the final beam current, this modulation is opposite in sign to the double charge exchange process.

2. POLARIZATION RESULTS

A light chopper modulated the laser beams at 100 Hz, and photon counting was gated with the lasers on and off. The gate lengths were identical for both laser states and shorter than the laser modulation times so that the Rb polarization had time to reach equilibrium. Two Ti:sapphire lasers each pumped by a 20 W argon ion laser produced up to 9 W of 795 nm light for optical pumping of Rb. Because the polarimeter measures proton polarization, it underestimates the H^- polarization by a few percent, since the proton beam is more affected by the unpolarized residual gas background.

Figure 3 shows the proton polarization and H^- current as functions of Rb thickness.[7] The Rb cell was designed to produce a smooth Rb-density distribution close to the extraction electrodes. This minimizes the effect of background hydrogen gas near the electrodes, and allows us to achieve relatively high beam polarization for very thin targets. The smooth distribution of Rb prevents the premature reduction of polarization by radiation trapping.[8,9] Figure 3 also shows the Rb polarization and the efficiency with which it is transferred to the ion beam, after correcting for unpolarized background beam seen at zero Rb thickness.

Polarization has also been measured as a function of laser frequency (see Fig. 4). In principle, the Lyman-α polarimeter is superior to the Faraday rotation method for optimizing the laser frequency. The polarimeter gives a direct measure of ion beam polarization and is averaged over the whole beam, rather than just sampling the Rb polarization along the small interaction volume of a probe laser.

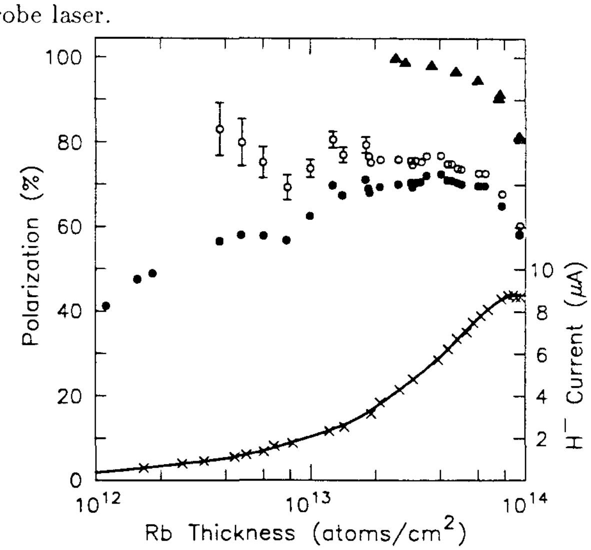

Fig. 3. Polarization, and H^- current measured at Faraday Cup 3, as functions of Rb thickness. Triangles; Rb polarization measured with the ion beam on. Solid circles; proton polarization measured in the Lyman-α polarimeter. Open circles; calculated proton polarization if the effect of unpolarized background current is removed. Crosses; H^- current, which had a background value of (0.32 ± 0.03) μA when the Rb cell was cold. The proton polarization was measured down to $\sim$30%, at a Rb thickness smaller than the estimated error of $\pm 5 \times 10^{11}$ atoms cm^{-2}.

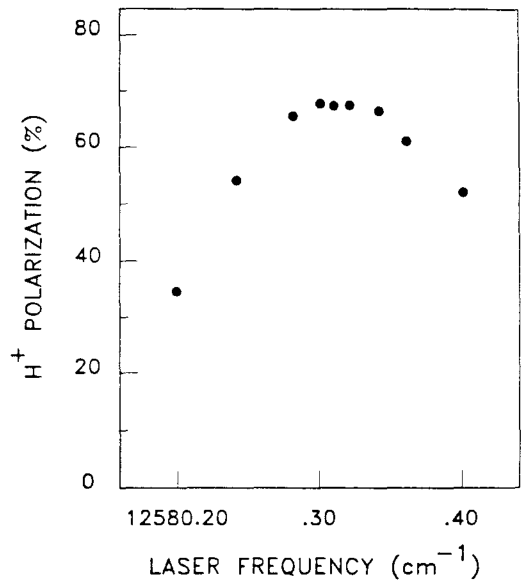

Fig. 4. Proton polarization as a function of pump laser frequency, for a single 5 W laser having a bandwidth (FWHM) of 0.1 cm^{-1}. The laser frequency was measured with a Burleigh WA-10 wavemeter.

Figure 5 shows the dependence of proton polarization on the magnetic field in the Rb cell. We observe that contrary to spin-orbit depolarization calculations,[10] the polarization is still rising significantly above 22 kG. Further study is required to decide if T is increasing at the highest fields, or if other factors are at play.

Figure 6 shows the polarization as a function of magnetic field in the ionizer cell. The theoretical difference in polarization between 1.5 and 2.0 kG is 1%, whereas we observe 2.5–3%. This is because the ionizer magnetic field drops at the edges of the Na vapour-density distribution, and the H^- ions produced there lose more polarization. The ionizer solenoid is being lengthened by 8 cm to improve the field uniformity.

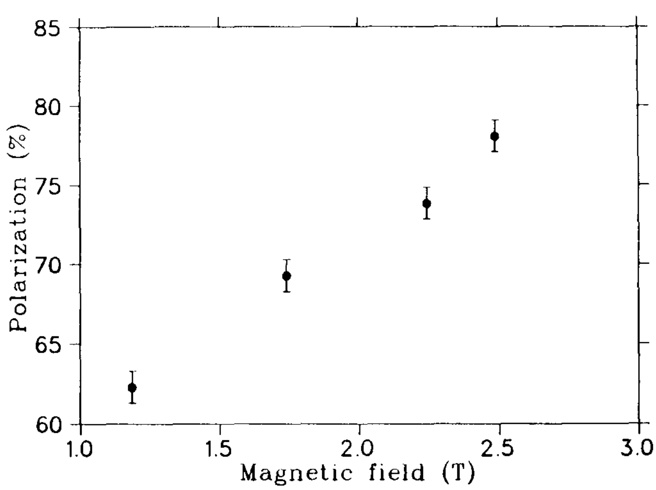

Fig. 5. Proton polarization as a function of magnetic field in the Rb cell.

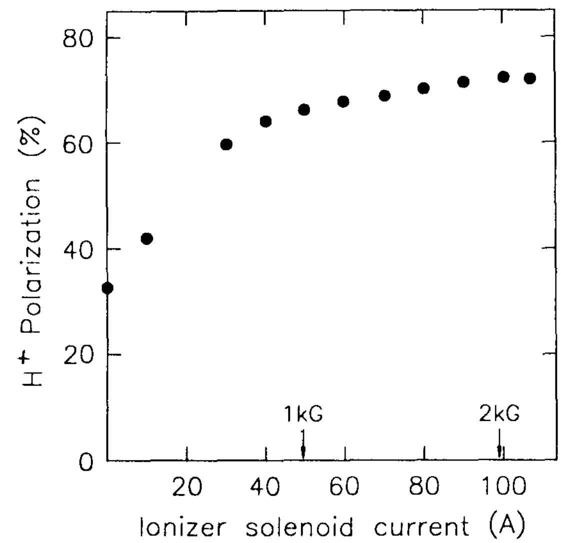

Fig. 6. Proton polarization dependence on ionizer-cell magnetic field.

Polarization was also studied as functions of hydrogen gas flow rate, beam energy and trim coil current (controlling the magnetic field gradient in the Sona transition region). At 25 kG in the Rb cell and 2.3 kG in the ionizer cell, at a beam energy of 2.8 keV, the highest proton polarization measured with the Lyman-α polarimeter was (80.1 $\pm$ 0.5)%, after optimizing all source parameters for polarization only.

3. CM RESULTS

When measuring CM, the voltage on the bender plates is reversed so that H^- beam enters the polarimeter. Current is measured either with Faraday Cup 3, or with Faraday Cup 2 (see Fig. 2). In the latter case CM can be measured simultaneously with polarization, while the current signal is applied as a normalizing correction to the polarimeter counts. The current signals were measured with a 4 MHz linear current digitizer and gated with the laser modulation as described above.

The results of CM measurements as a function of Rb thickness are shown in Fig. 7, where the CM is defined as

$$\frac{I_{\text{laser on}} - I_{\text{laser off}}}{I_{\text{laser off}}} \qquad (3)$$

Over the thickness range 3–8 $\times$ 10^{13} atoms cm^{-2} the CM rises linearly as expected for the double charge exchange process and shows quantitative agreement with the estimates above. At higher thickness the modulation of opposite sign is observed and at a thickness of 9 $\times$ 10^{13} atoms cm^{-2} has a maximum magnitude of about 1%. The sudden change from one dominant process to the other is surprising, as is complicated behaviour below 3 $\times$ 10^{13} atoms cm^{-2}.

In practice, one is interested in the difference of current between opposite spin states. We cannot measure such modulation directly, since the fast 100 Hz spin reversal system suitable for parity violation experiments has not yet been completed. We measured CM separately for up and down helicities. Figure 8 shows CM as a function of Rb polarization. A least squares quadratic fit shows that the CM is symmetric with helicity, as implied by Eq. 2, within an error of $\pm 1.0 \times 10^{-4} P^2$. Further measurements will be required to test this down to the 10^{-5} level.

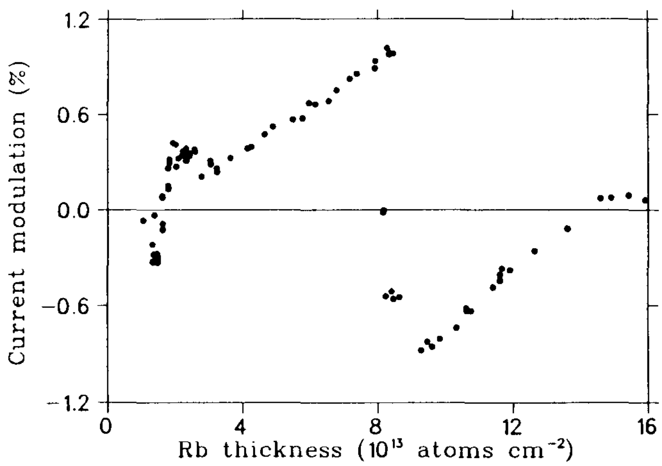

Fig. 7. Modulation of H^- source current between unpolarized and polarized conditions, as a function of Rb thickness.

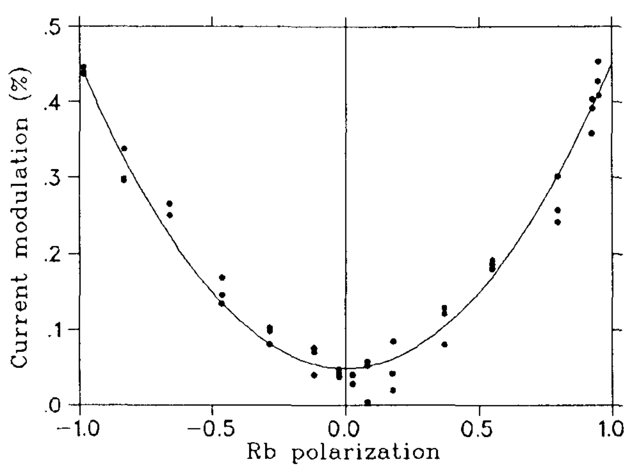

Fig. 8. Modulation of H^- current between polarized and unpolarized conditions, as a function of Rb polarization. The data were taken at a Rb thickness of 4×10^{13} atoms cm^{-2}. The polarization was varied by adjusting the frequency tune of the pumping lasers. The curve is a least squares fit to the data of $CM = a + bP^2$, where a and b are adjustable parameters. The standard error of b is $\pm$ 1.0 $\times 10^{-4}$.

4. CONCLUSION

The TRIUMF optically pumped H^- source has become a reliable producer of microamps of 75% polarized beam. The construction of a low-energy polarimeter allows us to further optimize and study OPPIS in an accurate and efficient way, showing that 80% polarization or more is within reach. Preliminary results on the modulation of ion current with spin helicity show that OPPIS is promising for use in parity violation measurements requiring modulation at or below the 10^{-5} level.

5. REFERENCES

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