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# CONVERSION EFFICIENCY OF A RING MAGNETRON IONIZER IN THE PONI-2 POLARIZED ION SOURCE

C. Meitzler

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Collider Accelerator Department

**Brookhaven National Laboratory**

**U.S. Department of Energy**

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Accelerator Division
Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

Accelerator Division
Technical Note

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## Introduction

The use of a ring magnetron as an ionizer to produce polarized $H^-$ at the AGS had been proposed[1] and the initial development has been completed. In this scheme, shown in Figure 1, a flux of polarized hydrogen atoms would enter a plasma consisting of $D^-$, $D^+$, and electrons supplied by a ring-shaped magnetron. The incident atomic beam would undergo a resonant charge exchange reaction, $H^\circ + D^- \rightarrow H^- + D^\circ$, to produce a negative ion beam for acceleration. The advantages of this type of ionizer compared to the existing $Cs^\circ$ colliding beam ionizer are:

(1) The charge exchange cross section for the $H^\circ - D^-$ reaction is 7.5 times larger than the cross section for the $H^\circ + Cs^\circ \rightarrow H^- + Cs^+$ reaction.
(2) The axial length of the ionization volume can be made shorter than the colliding $Cs^\circ$ beam interaction region, resulting in a larger acceptance for the atomic beam.
(3) The current of the $D^-$ beam from the magnetron may be at least an order of magnitude larger than the $Cs^\circ$ beam current.
(4) A plasma ionizer will not create a large thermal load on a cold atomic beam source. (This point is quite important for very cold atomic beam systems where high power refrigerators are not readily available.)

Initial tests of the ring magnetron ionizer on a test stand showed that the $D^-$ current reaching the center of the ionization volume could be as high as 700 mA.[2] The extracted unpolarized $H^-$ current was in excess of 500 μA with an estimated H° density of $10^{12}$ $cm^{-3}$. An estimate of the conversion efficiency on the test stand is 0.37 percent.

The ionizer assembly was moved to the PONI-2 polarized ion source to study its performance in an operational polarized ion source and investigate if any depolarization occurred during ionization. After installation, the extracted $H^-$ current was observed to be substantially lower than the currents obtained on the test stand. The measurements described in this Technical Note are a set of determinations of the ionization efficiency in PONI-2 for three different geometries of the anode apertures in the ring magnetron: (1) two slots per cathode groove where each slot spanned 90 degrees of arc (the geometry used in the test stand), (2) two sets of 1/2 mm diameter circular apertures per cathode groove where each set spanned 90 degrees of arc, and (3) one set of evenly spaced 1/2 mm diameter apertures for each cathode groove.

## Experimental Procedures

A determination of the conversion efficiency consists of two separate measurements: (1) a measurement of the atomic beam density at the position of the ionizer, and (2) a measurement of the extracted $H^-$ beam. A schematic drawing of the beam line is shown in Figure 2. The atomic beam originates in a room-temperature dissociator, passes through the ionization volume, an Einzel lens, a Wien filter, a second Einzel lens, and finally passing a retractable residual gas analyzer into a Faraday cup.

### Atomic Density in the Ionizer

The RGA Faraday cup current was calibrated as a function of $H_2$ density by admitting hydrogen gas into the vacuum chamber and measuring the RGA output signal. The pressure in the vacuum chamber was measured with a Bayard-Alpert gauge placed nearby. The real pressure was obtained by using the correction

$$P_{real} = S_G(P_{ind} - P_{back})$$

where $P_{back}$ is the initial background pressure (predominantly air), $P_{ind}$ is the indicated pressure and $S_G$ is the sensitivity of the gauge to hydrogen gas relative to air. For these measurements $S_G$ was taken to be 2.4. The pressures $P_{real}$ were then converted to $H_2$ densities. H° densities were obtained from the $H_2$ density calibration by using the ionization cross section for the H° relative to that of $H_2$. The correction employed is a division of the $H_2$ density by 0.6. The RGA output was sent to the signal averaging function of a LeCroy 9400 digital oscilloscope. The signal processing used in these measurements was a summed average over 100 pulses.

The dissociator gas pulse was 0.6 ms long with an inlet pressure of 160 Torr. The dissociator rf pulse was 10 ms long. The repetition rate was set to 0.5 Hz. The atomic beam density was measured with the RF ON and with the RF OFF for a background measurement. The ionizer was turned completely off.

## Ion Beam Measurements

Each of the ion beam measurements were made with the extraction and beam transport optics optimized for that particular run. The atomic beam incident to the ionizer was unpolarized. In each case, the deuterium inlet pressure was lowered as far as possible. A summary of the relevant source parameters is given in Table I.

The source Faraday cup was a deep cup with a -300 V electron suppression ring. The current in the source Faraday cup was measured by placing a 100 kΩ resistor between the cup and ground potential. A storage oscilloscope was used to measure the voltage developed across the resistor.

## Results and Discussion

The atomic beam density at the RGA was $3.2 \pm 1.5 \times 10^9$ atoms/cm$^3$. Using a $1/z^2$ dependence for the density, z being the distance along the beam axis, this yeilds a density of $3.2 \pm 1.5 \times 10^{11}$ atoms/cm$^3$ at the position of the ionizer. Assuming that the velocity of the H° emitted by the dissociator is $3.0 \times 10^5$ cm/sec,[4] the flux entering the ionization volume is $2.7 \pm 1.3 \times 10^{17}$ atoms/sec. The errors quoted are estimates of the errors associated with the calibration of the RGA Faraday cup as a function of $H_2$ density.

The conversion efficiency will be defined as

$$\eta_I = R_{out}/R_{in} = I_{xt}/env_o A$$

where $R_{out}$ ($R_{in}$) are the rates at which hydrogen ions (atoms) enter and leave the charge exchange plasma, $I_{xt}$ is the extracted $H^-$ current, $v_o$ the mean atomic velocity, n the density in the absence of gas scattering and A is the cross-sectional area of the ionization volume. The extracted $H^-$ current for the slotted anode typically averaged 15 μA yielding a conversion efficiency of (0.034 ± 0.017) percent. The anode with clustered circular apertures yielded an extracted current of 40 μA resulting in an efficiency of (0.095 ± 0.046) percent. The anode with distributed circular apertures yielded an extracted current of 50 μA with a conversion efficiency of (0.12 ± 0.06) percent. These conversion efficiencies are not corrected for the transport efficiency of the beam line. Measurements of the source current with a positive ion beam indicate that the transport efficiency is reasonably high and did not account for the observed loss of conversion efficiency.

Table I shows that the anodes with circular apertures have roughly half the area of the slotted anode. The $D^-$ current entering the ionization volume, and by extension the $H^-$ current extracted from the ionizer, should be proportional to the anode aperture area; therefore, one would expect the efficiency of the circular aperture anode to be lower than the slotted case. The opposite effect was seen. Furthermore, it should be noted that the best output for a given geometry occurs when the deuterium gas inlet valve pulse is short and the deuterium inlet pressure is as low as possible while maintaining a stable magnetron discharge. The highest ionization efficiency, that of the distributed circular aperture geometry, occurred when the deuterium inlet pressure 200 Torr, was one half the inlet pressure needed by the slotted anode, 400 Torr.

Initial tests of the ionizer on the test stand saw approximately one-quarter of the $H^-$ output expected from the design calculations. The authors mentioned that the loss of both $H^\circ$ and $H^-$ due to gas scattering may have been a concern on the test stand.[2] In the more restricted PONI-2 ionizer vacuum chamber, the role of gas scattering may have become the dominant loss mechanism.

## Summary

The ring magnetron ionizer suffered a severe loss of efficiency when installed in the ionizer chamber of the PONI-2 ion source.

Adjustments to the anode geometry have improved the conversion efficiency from the ionizer, but have not restored it to the level seen on the test stand. The pumping speed in the ionizer region of PONI-2 is believed lower than it was in the test stand, and high deuterium pressure in the ionization volume plays an important role in reducing the overall conversion efficiency of a ring magnetron based ionizer in PONI-2. Further studies on the effect of gas scattering on the atomic beam and the role of the local pumping speed are in progress and will be reported in a subsequent Technical Note.

## Acknowledgments

I would like to thank J. Alessi, A. Hershcovitch, and A. Kponou for many useful conversations about a wide variety of subjects related to polarized ion sources. Thanks to D. McCafferty for all his technical assistance with PONI-2.

## References

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[2]J.G. Alessi, Helv. Phys. Acta 59, (1986), 547.

[3]J.G. Alessi, A. Kponou, and Th. Sluyters, Helv. Phys. Acta 59, (1986), 563.

[4]W. Gruebler, Proc. Polarized Proton Ion Sources, Ann Arbor, MI, A.D. Krisch and A.T.M. Lin, Eds., AIP Conf. Proc. No. 80 (AIP, New York, NY, 1982), 69-77.

TABLE I

Typical Operating Parameters for Ionizer and Beam Transport System

| | |
|---|---|
| Total Anode Area ($mm^2$) | |
| Slotted Anode | 19.9 |
| Circular Aperture Anodes | 11.7 |
| Inlet Pressure (Torr) | |
| Slotted | 400 |
| Clustered Circular | 350 |
| Distributed Circular | 200 |
| Valve Pulse Width (ms) | 0.6 |
| Magnetic Field (Gauss) | 750 |
| Upstream Grid (V) | - 100 |
| Downstream Grid (V) | 120 |
| Int. Electrode (kV) | 3.5 |
| Extraction (kV) | - 10 |
| Einzel Lens #1 (kV) | - 7.5 |
| Wien Filter Magnet Current (A) | 40 |
| Wien Filter Plate Voltage (V) (tuned to mass 1 peak) | 980 |
| Einzel Lens #2 (kV) | - 5.5 |

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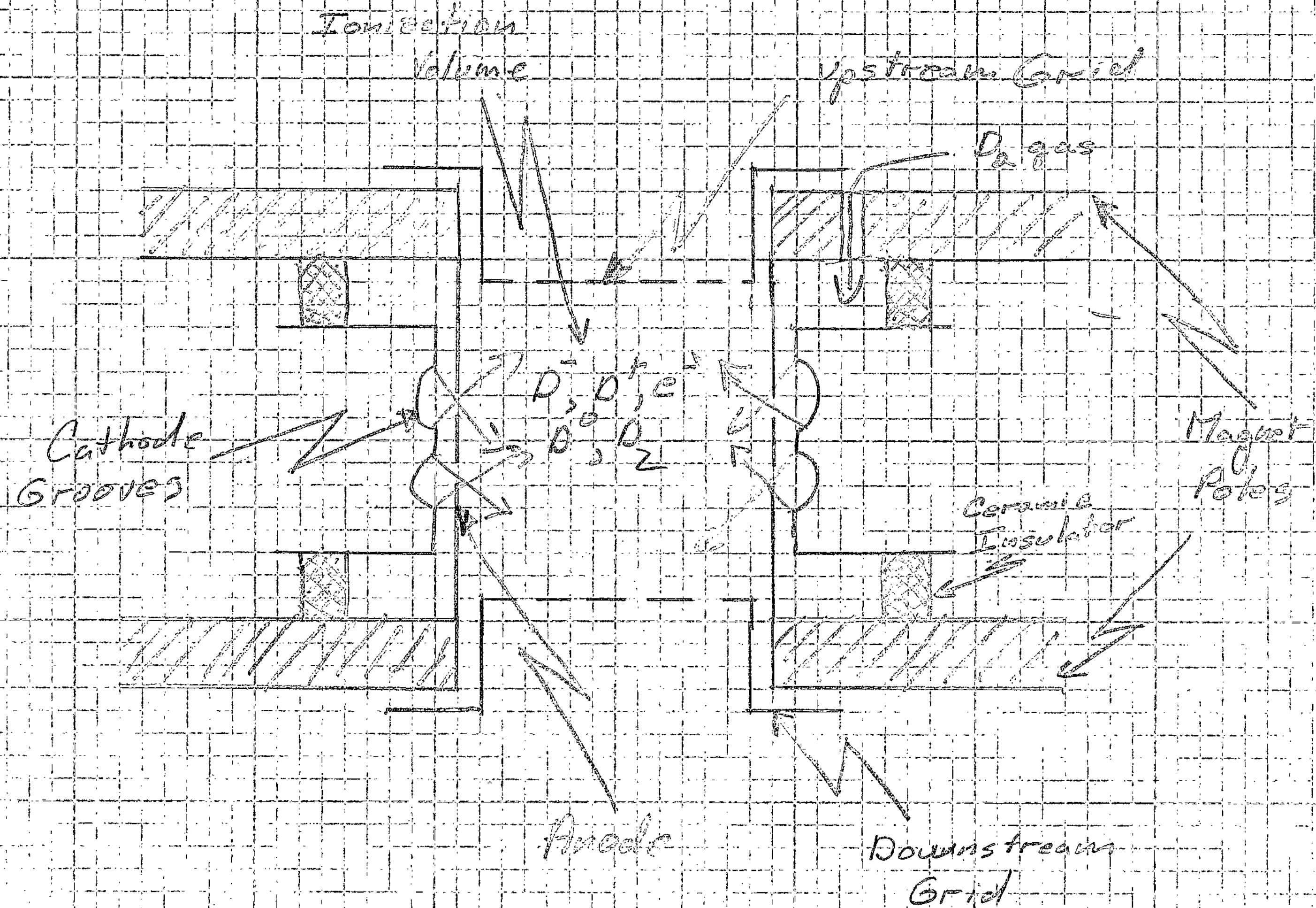
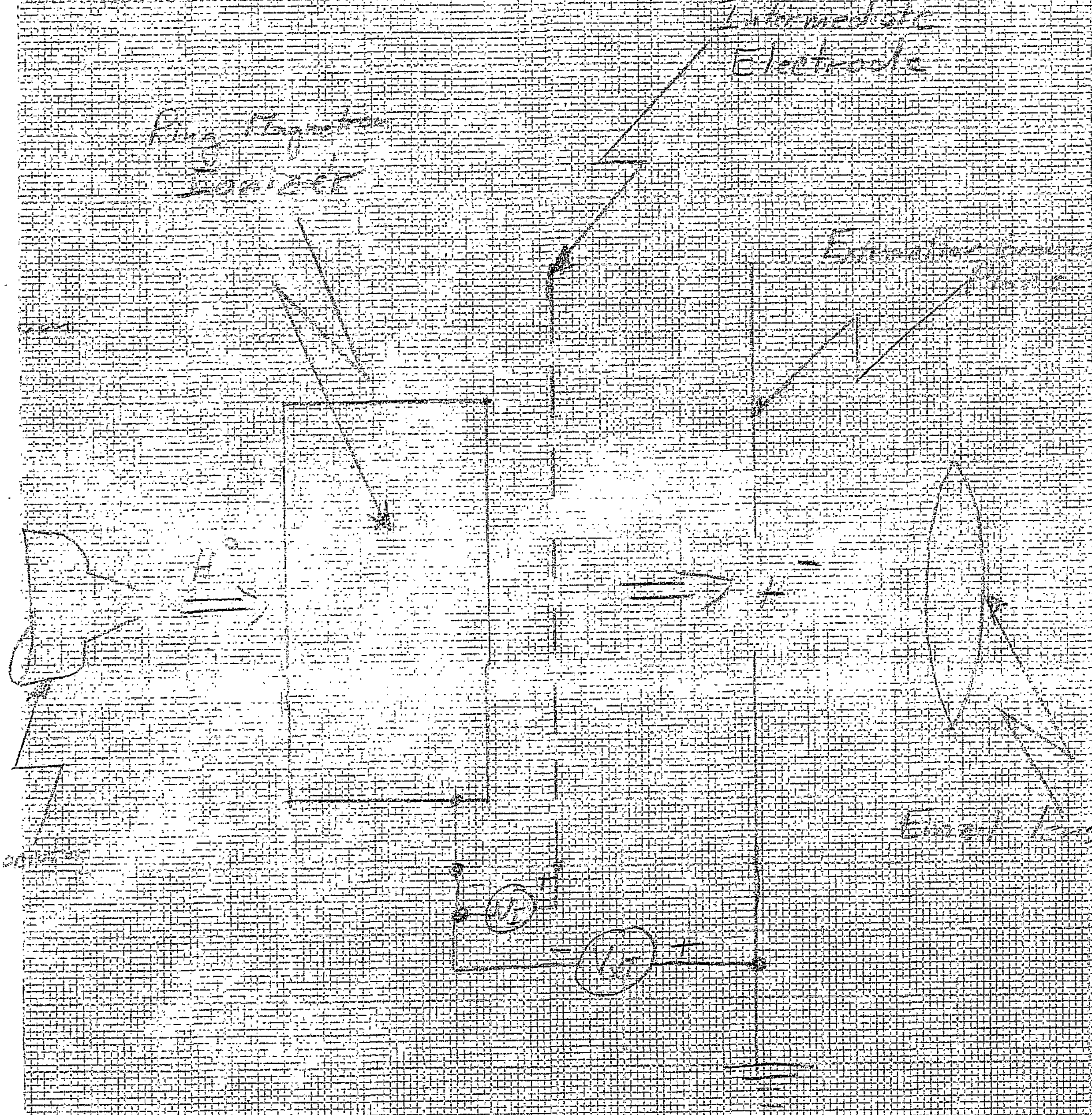



Figure 1 – Schematic of ring magnetron ionizer

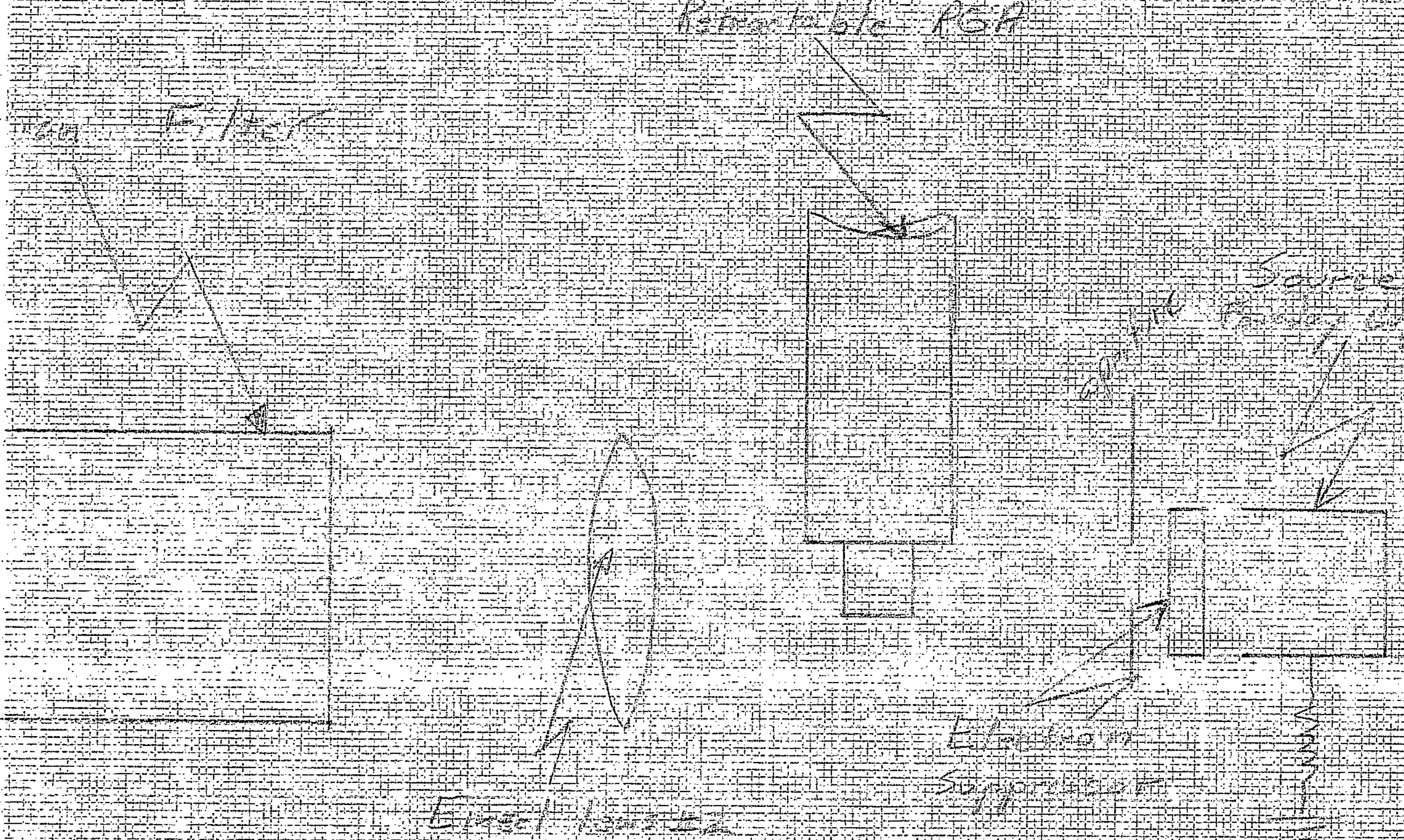



$V_{HT}$ – 10 kV Extraction

$V_I$ – Intermediate electrode

Not to Scale

Figure 2




Schematic drawing of PONI-2 beam line used in these measurements.