

AN EFFICIENT IONIZER FOR POLARIZED H^- FORMATION*

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BNL--36482

DE85 013294

Summary

An ionizer is under development for a polarized H^- source based on the resonant charge exchange reaction $H^+ + D^- \rightarrow H^- + D^+$. The H^+ beam passes through the center of a magnetron surface-plasma source having an annular geometry, where it crosses a high current (~ 0.5 A), 200 eV D^- beam. Calculations predict an $H^+ + H^-$ ionization efficiency of $\sim 7\%$,¹ more than an order of magnitude higher than that obtained on present ground state atomic beam sources. In initial experiments using an unpolarized H^+ beam, H^- currents in excess of 100 μ A have been measured. While the ionization efficiency is now only about the same as other methods (Cs beam, for example), the results are encouraging since it appears that by injecting positive ions to improve the space-charge neutralization, and by improving the extraction optics, considerable gains in intensity will be made. We will then use this ionizer with a polarized H^+ beam, and measure the polarization of the resulting H^- beam. If no depolarization is observed this ionizer will be combined with an atomic beam, cooled to 5-6 K,² to give a polarized H^- beam expected to be in the milliamperage range for use in the AGS.

Introduction

The AGS polarized H^- source presently produces currents on the order of 25 μ A.³ While this is a high intensity for H^- , currents several orders of magnitude higher could be used in the AGS. There is, therefore, a source development program in progress in which we are attempting to demonstrate the feasibility of two improvements. One is to improve the H^+ density and flux in the ionization region by cooling the atomic hydrogen beam to $\sim 5^\circ$ K.² The second is to improve the ionization efficiency by using an intense D^- beam rather than the Cs^+ beam for H^+ ionization.

The use of the resonant charge exchange reaction $H^+ + D^- \rightarrow H^- + D^+$ was suggested by Haerberli⁴ as a promising way of ionizing polarized hydrogen atoms, due to the large cross section, and the availability of high current D^- sources. The difficulty encountered when trying to devise an ionization scheme using this reaction is the deleterious effect of the space charge forces from the intense D^- beam. Drawing on past experience in the development of high intensity H^-/D^- ion sources, we are presently testing a novel ionizer geometry based on a magnetron surface-plasma source.

The source, shown schematically in Figure 1, has an annular geometry, with the cathode as the outer-, and the anode as the inner ring. D^- ions are produced on the low work-function cathode, and then accelerated toward the anode with the ~ 200 V cathode voltage. The D^- ions then pass through slits in the anode and into the center of the ring, with no external extraction being required. D^+ ions from the high

density source plasma could diffuse out the anode slits and space charge neutralize the D^- ions in the central, electric field-free region of the ionizer. The polarized H^+ beam passes axially through the center of the ring magnetron, and is ionized by charge exchange with the D^- . The ~ 1 kG magnetic field required for the magnetron operation is also sufficient for preserving the beam polarization during ionization. H^- ions are then extracted from the opposite end, and mass analyzed to eliminate any D^- component.

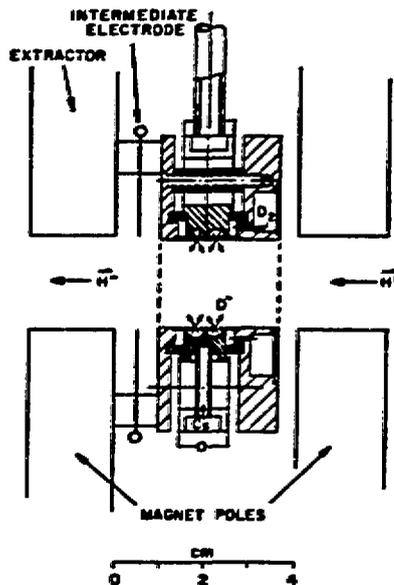


Fig. 1 - Schematic of the ring magnetron ionizer.

This ionizer is very compact, having a diameter of 1.9 cm, and an axial length of ~ 2 cm. This short length (compared to the 35 cm ionizer length using the cesium beam in the present AGS polarized source), should lead to a higher H^+ flux in the ionization region, since the atomic beam is essentially diverging after the last sextupole magnet.

There are many processes which must be included when trying to calculate the ionization efficiency (H^- flux out/ H^+ flux in) for such an ionizer.¹ In addition to the 200 eV D^- ions and the ~ 1 eV D^+ ions in the center of the ring, there are also thermal D^+ atoms, and 200 eV D^+ atoms coming from charge exchange of D^- with D^+ inside the magnetron plasma

*Work performed under the auspices of the U.S. Department of Energy.

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region. The results of calculations, which include the most important destruction processes, and assuming a D^- current of 0.5 A, give an ionization efficiency of $\sim 7\%$. This is a gain of more than a factor of 10 over the Cs beam ionizer. Important questions to be answered in initial experiments were how efficient the space charge neutralization would be, and if gas scattering of the H^- and H^0 in the relatively high background D_2 pressure outside the magnetron would be a problem.

The Ring Magnetron Source

The ring magnetron has a geometry inverted from typical magnetron surface-plasma sources, in that the cathode is the outer and the anode is the inner of two concentric rings. The molybdenum cathode is 2.2 cm inner diameter and 0.9 cm long (cathode area = 6.2 cm^2), and two grooves in the cathode geometrically focus the surface-produced D^- into slits in the anode. The anode ring is 0.5 mm thick, with 0.5 mm wide slits and a total slit length of 9 cm. The gap between the cathode and anode is 1 mm, and there is no expansion gap as is normally used in magnetrons to reduce the extracted electron current. Since in the present geometry there is no D^- extraction field, extraction of electrons is not a problem, and therefore the distance from the cathode to the anode slit was kept small in order to minimize destruction of D^- in the dense source plasma and to minimize charge exchange of the fast D^- with D^+ in the source. Having the slits so close to the source plasma should also facilitate diffusion of plasma D^+ ions out of the source for space-charge neutralization of the D^- . Macor rings provide insulation between the cathode and anode. Deuterium gas is fed into the gap uniformly through eight holes in one of the anode and end plates. Cesium vapor is fed uniformly into the source through four equally spaced holes in the cathode. The source operates in an axial magnetic field of ~ 1 kG.

For testing of the magnetron, a 0.5 cm diameter rod was inserted into the center of the ring to measure the D^- beam current. A wire spiralled in a 1.0 cm diameter around the rod acted as a biased grid. Self-extracted D^- currents of up to 0.7 A were detected in the center of the ring, with 30-40 A arc current and an arc voltage of ~ 200 V. The pulse width for these experiments was 5-25 ns and rep-rate was ~ 0.4 Hz.

Charge Exchange Ionization Experiments

As a first test of the feasibility of the ionizer concept, the magnetron source was mounted in a test box with a hydrogen dissociator, to measure the ionization efficiency without the added complication of polarizing the atomic beam. A schematic of the test setup is shown in Figure 2. Hydrogen is fed into an rf dissociator operating at 20 MHz. The inlet gas flow is monitored by a flowmeter. The gas can be fed in steady-state or pulsed, and the rf is pulsed. The pyrex dissociator bottle is identical to that used on our AGS polarized ion source,³ and has a 3 mm diameter nozzle aperture. A 5 mm diameter skimmer is located approximately 3 cm from the tip of the dissociator, and this first stage is pumped by a 2500 l/s oil diffusion pump. The center of the magnetron is 7 cm from the skimmer aperture. The skimmer can also be removed and the dissociator close-coupled to the magnetron entrance (5.5 cm from the nozzle to the

center of the ionizer). Both source magnet poles are isolated from the magnet coil, and a negative bias can be placed on the entrance magnet pole to prevent loss of H^- from this end, and a 1200 V bias is placed on the exit magnet pole to act as a crude extractor. There is also an intermediate electrode on the extraction end. Grids of 85% transparency mounted on both ends of the magnetron prevent any extraction field penetration into the ionization region. After extraction there is an $r=10$ cm analyzing magnet, with a 3.3 cm gap, and finally the beam is measured on a 1 cm wide Faraday cup. A 1 mm wide by 1 cm thick collimator can be inserted before the analyzing magnet to get better mass separation between extracted H^- and D^- . More recently, a gridded einzel lens was added after the extractor in an attempt to improve the beam optics.

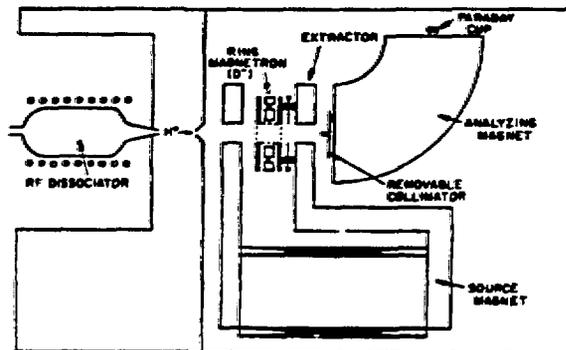


Fig. 2 - Experimental setup for measuring the H^- production.

The hydrogen discharge is monitored by using a fiber optic cable near the dissociator nozzle to transmit light to a 6563 Å analytical line filter, allowing the measurement of the intensity of the H_{α} line. While the optimum operating dissociator pressure is higher than that giving the maximum optical intensity, the monitor is still useful for optimizing the dissociator rf.

Results

The initial experiments have been performed without the skimmer after the dissociator, and with the distance from the nozzle to the center of the ring magnetron of 5.5 cm. With the D^- magnetron pulsing, the hydrogen gas flowing steady state through the dissociator, and with the dissociator rf turned off, magnet scans show an extracted D^- peak, while an H^- peak is only barely detectable. However, when the dissociator rf is turned on, so H^- is now injected into the ionizer, an H^- peak from the resonant charge exchange is clearly seen, often similar in magnitude to the D^- peak. In Figure 3, the upper trace is the Faraday cup current with the analyzing magnet set for H^- . The D^- pulse width is 20 ns, and with the dissociator off there is 3 nA detected since the H^- is in the tail of the D^- peak (no beam collimation). On the next pulse, the rf is turned on ~ 10 ns into the pulse (shown by the signal from the dissociator H_{α} line detector on the lower

trace), and an H^- current of 20 μA is measured. An H^- current of up to 40 μA has been detected on the 1 cm wide Faraday cup, and scanning the peak with the magnet and integrating gives currents in excess of 100 μA . Considering the poor extraction optics, the total extracted H^- could well be significantly higher. The extraction power supply current, which includes electrons, is ~ 5 mA.

H^- currents of 50-100 μA can be obtained with D^- currents of only ~ 20 mA, and increasing the D^- current to several hundred milliamperes does not significantly increase the H^- current, and sometimes even reduces the extracted H^- . This limit at such low D^- currents cannot be explained readily by H^- and H^0 destruction processes, since this limit is much too

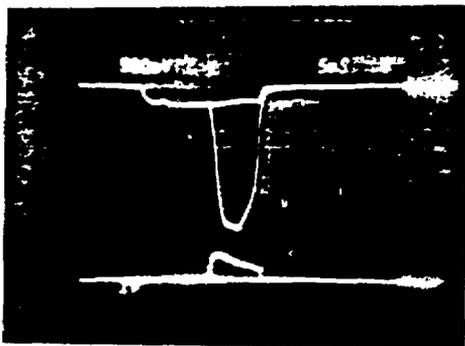


Fig. 3 - Upper trace shows H^- produced by resonant charge exchange (10 $\mu A/V$). The lower trace shows the H_α light from the rf dissociator.

low even assuming all destruction cross sections to be an order of magnitude larger than the values (measured or extrapolated) used in the calculations. It appears, rather, that the problem is due to space charge in the ionizer or extraction region. Several other observations support this. The D^- current frequently decreases when the dissociator is pulsed on, by approximately the amount of the additional H^- current. Also, when xenon gas was fed in near the ionizing region to a pressure of 3×10^{-3} Torr, the H^- current increased by $\sim 40\%$, presumably due to the improved space charge neutralization from Xe^+ ions produced by ionization by the D^- . In order to improve the space charge neutralization, we are now preparing to add thermal Cs^+ ions, produced by surface ionization, in the ionizing region.

We can not yet make a good estimate of the H^0/H^- ionization efficiency, since the H^0 flux through the ionizer is still unknown. A rough estimate can be made from the measured H_2 gas flow into the dissociator of ~ 0.25 Torr \cdot l/s . If 80% dissociation is assumed, and a $\cos^2 \theta$ H^0 gas flow out of the dissociator, the H^0 flux through the ionizer would be 3×10^{17} atoms/s. This leads to an estimated ionization efficiency of $\sim 0.2\%$.

Conclusion

A pulsed magnetron surface-plasma source has been built which produces a self-extracted D^- current of up to 0.7 A. Initial experiments with this ring magnetron ionizer have produced H^- currents on the order of 100 μA by charge exchange of D^- and H^0 . This ionization efficiency, estimated to be $\sim 0.2\%$, is well below the expected efficiency of $\sim 7\%$. Space-charge in the ionizing region, which has always been a concern in proposed schemes using D^- charge exchange, appears to be limiting the extracted current. Adding xenon background gas improved the H^- output, presumably due to partial space-charge neutralization by Xe^+ . This makes us hopeful that modifications now being made to improve the space-charge neutralization by adding surface ionized Cs^+ will lead to significant improvements in the H^- intensity. The ionizer is still in the early stages of development, and will surely benefit from refinements in the beam extraction as well. In spite of this, the efficiency already appears to be comparable to our Cs^+ beam ionizer, and offers the advantage of a much shorter ionization length.

We are presently preparing the atomic beam stage of a polarized H^+ source (from the ZGS), and following the optimization of the ring magnetron, the ionizer will be used with the polarized H^+ beam. The polarization of the extracted H^- beam will then be measured at 20 keV using a polarimeter developed by Yale University.⁵ Assuming the beam polarization is preserved, and depending on the results of the 5°K atomic beam tests, the ionizer and cold atomic beam would be combined in a source producing an estimated polarized H^- current of 3.5 mA.

Acknowledgments

The support of all in the Advanced Source Development Group is appreciated, and particularly the help of R. Clipperton and V. Kovarik.

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