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A RING-MAGNETRON IONIZER FOR POLARIZED NEGATIVE-ION SOURCES*

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I. Introduction

It has been realized for some time¹ that the use of the reaction

to produce polarized H⁻ ions could be very efficient. While intense H⁻/D⁻ ion sources exist,² one encounters space-charge problems when trying to put this scheme into practice. In this paper, a simple method, which uses a self-extracted D⁻ beam from a ring magnetron source, is proposed. The basic idea will be presented in the following section. In Section III, approximate numbers will be given and the expected intensity will be estimated. The method not only offers improvements in intensity, but equally important, improvements in reliability and lifetime.

II. Proposed Configuration

Figure 1 shows the proposed configuration. The polarized atomic beam travels into a solenoid containing a pulsed magnetron negative ion source. D⁻ ions are self-extracted from the magnetron, coming out from the curved cathode with ~ 200 eV of energy. Because there are no electric fields outside the source, D⁺ ions will also diffuse from the source to space charge compensate the D⁻ beam and any H⁻ ions. Polarized H⁻ ions are produced by the charge exchange reaction given in Equation 1. They are then extracted at the exit of the solenoid. A deflection magnet (or Wien filter) separates the H⁻ beam from any extracted D⁻ ions or electrons.

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Although one can easily imagine other configurations for the magnetron source, a ring magnetron is proposed here because one can get a high current in a relatively compact structure. The cathode (with one or more focusing grooves) is the outer ring, and the anode is the inner ring. Ions are extracted from slits in the anode. We have recently learned that a magnetron-based ionizer scheme with several similarities has been considered by G. Clausnitzer.³

Because of the large cross section for the reaction in Equation 1, particularly at these low energies, and the high intensity of the D⁻ ion source, one can expect a considerable improvement in the polarized beam intensity. Also, one would replace the Cs source and Cs vapor neutralizer used in the present BNL polarized source⁴ with a simple pulsed magnetron source, the reliability of which has been proven. Rather than the ~ 30 cm long interaction region found when Cs charge exchange is used, the interaction region will only be ~ 2 cm long. With the placement of this immediately after the rf transition units, the atomic beam density should be significantly higher than the average density one gets over the 30 cm interaction region. One will be less sensitive to chromatic aberrations in the atomic beam, and should be able to find a configuration of sextupoles giving higher H⁰ density in this short interaction region.

III. Feasibility

In the following analysis, the atomic beam parameters used are a rough estimate of the present performance of the BNL source (pulsed operation and cooled nozzle), i.e., a density of $\sim 3 \times 10^{11} \text{ cm}^{-3}$, $\bar{v} = 1.5 \times 10^5 \text{ cm/sec}$, and atomic beam diameter of 1.6 cm.

Based on the performance of the Mk III magnetron source⁵ (with cathode grooves, but not asymmetric), one can estimate the performance of the ring magnetron. For discussion, we choose the following source dimensions. The cathode will have an inner diameter of 2.5 cm, 1 cm wide, and two grooves. The anode diameter is 1.9 cm, and the solenoidal field strength is 800 Gauss. Under normal operating conditions, the total extracted current would be ~ 1A. Based on previous measurements of the energies of ions extracted from a Mk III magnetron,⁶ one could expect ~ 50% of this current, or 0.5A, to come out as self-extracted D⁻ ions.

The 200 eV D⁻ ions pass approximately across the diameter of the H⁰ beam. The cross section for the reaction in Equation 1, for 200 eV D⁻ ions, is $\sigma \sim 6 \times 10^{-15} \text{ cm}^2$. Therefore, the number of D⁻ ions charge exchanging as they pass through the atomic beam (which equals the number of H⁻ ions created), is

$$I = I_{D^-} (1 - e^{-n_{H^0} \sigma l}) = 2.87 \times 10^{-3} I_{D^-} = 1.44 \text{ mA}$$

The D⁻ ions are actually deflected slightly by the magnetic field ($r_{D^-} = 2.8 \text{ cm}$) and therefore do not travel straight along the diameter. Also, the ions come out of the source with a spread of angles along the H⁰ beam direction, increasing the actual D⁻ path length l somewhat relative to the value used ($l = 1.6 \text{ cm}$). The H⁻ current (1.44 mA) is 10% of the incident H⁰ flux, and therefore one can neglect the decrease in H⁰ flux along the interaction length.

The maximum H⁻ density ($\sim 4 \times 10^9 \text{ cm}^{-3}$ at the end of the interaction region) is more than three orders of magnitude less than the plasma density in the source, and $\sim$ one order of magnitude less than the self-extracted D⁻ density. Therefore, this current should be space-charge compensated along with the D⁻ ions. In addition, the ionization of background D₂ by 200 eV D⁻ ions should contribute significantly to the space charge neutralization. If required, a small amount of Kr could be added in the interaction region, which would aid the space charge compensation.

It is convenient now to switch frames of reference to consider the destruction of the H⁻ ions as they pass through the ring magnetron. The effective line density of D⁻ ions seen by the polarized beam is

$$n_{D^-} l \sim 1.9 \times 10^{11} \text{ cm}^{-2}$$

If one has space charge compensation, then

$$n_{D^+} + n_{D_2^+} = n_{D^-} + n_{H^-}$$

Therefore, $(n_{D_2^+} + n_{D^+}) \ell \sim 1.9 \times 10^{11} \text{ cm}^{-2}$. It is estimated that due to the gas flow out of the source, $n_{D_2} \ell \sim 4 \times 10^{14} \text{ cm}^{-2}$. If one assumes 1% D, then $n_D \ell \sim 4 \times 10^{12} \text{ cm}^{-2}$. Finally, there are 200 eV D atoms coming out of the source, produced by charge exchange of D^- ions with D inside the source. Since we are assuming 50% of the D^- ions come out as fast, self-extracted ions, then there should be an approximately equal number of fast atoms coming out of the source, i.e., $n_{D_{\text{fast}}} \ell \sim 1.9 \times 10^{11} \text{ cm}^{-2}$. Important destruction reactions and their cross sections are summarized in Table 1. Several of these cross sections have large uncertainties, and may be extrapolations of the cross sections measured in the references.

Because the H^- ions are produced along the whole interaction length, all ions do not travel through the full interaction region. The equation for the final H^- current, after destruction processes are included, is then

$$I(H^-) = I_0(H^-) \frac{1}{\sum n \sigma \ell} (1 - e^{-\sum n \sigma \ell})$$

$$= 0.79 I_0(H^-) = 1.14 \text{ mA}$$

While H^- destruction does not seem to be a problem, scattering of the thermal H^0 and H^- beams by the background gas could cause a significant reduction in extracted intensity. As mentioned previously, the line density $n_{D_2} \ell \sim 4 \times 10^{14} \text{ cm}^{-2}$. From attempts to measure the atomic beam attenuation versus background pressure in the present polarized source, it appears that this gas scattering could cause a

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reduction in the H^- intensity by an order of magnitude. While the applicability of this measurement to the proposed configuration is uncertain (we should be less sensitive to small angle scattering), and the actual pressure outside the source is uncertain, this gas scattering is a concern.

IV. Conclusion

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An ionization scheme has been proposed which could increase the H^- intensity by one to two orders of magnitude using the existing BNL atomic beam stage. Key questions are how well the beam can be space charge neutralized, and the effect of gas scattering. While it is difficult to predict the final intensity, fortunately the actual experiment is relatively simple. Even if one gets only modest gains in intensity, the improvements in reliability should be very significant.

Another longer range option would be to use an HCD source¹² to produce the self-extracted D^- beam. The advantage of this approach would be the lower operating pressure, and the possibility of operating steady state, which is often a requirement for polarized sources.

Table 1

<u>Reaction</u>	$\sigma_{\text{eff}} = \frac{\sigma_{\text{v rel}}}{v}$ $\frac{\text{H}^\circ}{\text{H}^\circ}$	<u>$n\sigma_{\text{eff}}^2$</u>	<u>Reference</u>
$\text{H}^- + \text{D}^+ \rightarrow \text{H}^\circ + \text{D}^\circ$	] $\sim 10^{-12}$	0.19	7
$\text{H}^- + \text{D}_2^+ \rightarrow \text{H}^\circ + \text{D}_2$			8
$\text{H}^- + \text{D}_2 \rightarrow \text{H}^\circ + \text{D}_2 + e$	negligible	--	
$\text{H}^- + \text{D} \rightarrow \text{H}^\circ + \text{D}^-$	$\sim 3 \times 10^{-14}$	0.12	9
$\text{H}^- + \text{D} \rightarrow \text{HD} + e$	1.5×10^{-14}	0.06	10
$\text{H}^- + \text{D} \rightarrow \text{H}^\circ + \text{D} + e$	negligible		
$\text{H}^- + \text{D}_{\text{fast}} \rightarrow \text{H}^\circ + \text{D}_{\text{fast}}$	5.6×10^{-13}	0.11	9
$\text{H}^- + \text{D}^- \rightarrow \text{H}^\circ + \text{D}^- + e$	$\sim 9 \times 10^{-15}$	<u>0.002</u>	11

$$\sum n\sigma_{\text{eff}}^2 = 0.48$$

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Figure 1 - Schematic of the interaction region using a self-extracted D^- beam from a ring magnetron.

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