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### **Publication Date**

1980-10-01

Peer reviewed

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## Accelerator & Fusion Research Division



CONF-801068--19

Presented at the Brookhaven National Laboratory Second International Symposium on the Production and Neutralization of Negative Icns and Beams, Upton, NY, October 6-10, 1980

 $\mathrm{H}^-$  ion formation from a surface conversion type ion source

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October 1980



Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

DISCLAMER

LBL-11638

#### H" ION FORMATION FROM A SURFACE CONVERSION TYPE ION SOURCE\*

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#### Abstract

нions have been Volume-produced extracted from a multi-cusp ion source by using a standard extraction system. In addition, a molybdenum converter is installed in the source to generate surface-produced H<sup>-</sup> ions. The H<sup>-</sup> ion yield is measured by a mass spectrometer. Without cesium, the production mass of H- ions by the surface process is very or n ions by the surface process is very small compared with those generated by volume production. However, the presence of cesium car, greatly enhance the surface production yield. The energy spectrum shows that the surface-generated H<sup>+-</sup> ions contain two surface-generated H<sup>-</sup> ions contain two distinct groups when cesium is added to the discharge. The energy of one group is essentially that of the sheath potential and appear to be produced by a desorption process. The second group of  ${\rm H}^-$  ions have slightly higher energies and appear to be formed by a process. Different types reflection of converter materials have also been tested.

#### Introduction

In order to heat plasmas in future fusion reactors, the required neutral beam energy will greater than 150 keV. The hiah be neutralization efficiency (-60%) of H<sup>-</sup> or D<sup>-</sup> ions makes them favorable to form neutral beams with energies in excess of 150 keV. There are different approaches production of negative ions.<sup>2,3</sup> for the H.ions can be extracted , rectly from a hydrogen discharge plasma. Low-energy positive hydrogen or deuterium ions can be converted into negative ions by double charge exchange in a sodium or cesium cell. There are also H<sup>+</sup> ion sources that are based on surface interactions.

It has been reported that there is a substantial quantity of H<sup>-</sup> ions in a hydrogen discharge plasma.<sup>4</sup> The purpose of this experiment is to compare the amount of H<sup>-</sup> ions extracted directly from a multi-cusp source with that generated by plasma surface interactions, principally via desorption or reflection. In order to optimize the surface production yield of H<sup>-</sup> ions, different converter materials have been studied under the same gas pressure, cesium coverage, discharge.



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### Fig. 1 Schematic diagram of the multi-cusp negative ion source.

#### Experimental Setup

A schematic diagram of the experimental arrangement is shown in Fig. 1. The device is a cylindrical multi-cusp ion source<sup>5</sup> (20 cm diam by 14 cm long) with the open end enclosed by a three-grid extraction system. The chamber is surrounded externally by 10 columns of samarium-cobalt magnet ( $g_{max} \approx 4 \ kG$ ) to form a line-cusp configuration for primary electrons and plasma confinement.<sup>6</sup> A steady state hydrogen plasma is produced by primary ionizing electrons emitted from two 0.05 cm diameter tungsten filaments which are biased at -60 V with respect to the source chamber wall (anode). No actual source pressure has been But in normal operation, the measured nressure indicated by a gauge located downstream after the mass spectrometer was 2 x 10<sup>-4</sup> Torr. The H<sup>-</sup> ions in the hydrogen plasma is extracted by means of a standard Berkeley accel-decel electrode system with the first (plasma) grid masked down to an extraction area of 0.2 x 2 cm<sup>2</sup>. This plasma grid is biased positively at a potential Yg with respect to the anode which in turn is

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maintained at a negative potential  $V_a$ relative to ground. The center and the outermost grid are both grounded electrically to extract and accelerate the H<sup>-</sup> ions. A compact magnetic-deflection mass spectrometer<sup>-1</sup> is installed just outside the extractor to detect the H<sup>-</sup> ions.

In order to generate surface-produced H ions, a moveable, concave molybdenum converter (3 cm high by 5 cm long) is inserted into the plasma through a high-voltage insulator mounted on the end flange. By biasing the converter negatively V<sub>c</sub> with respect to the anode, positive ions from the plasma are accelerated across the sheath and strike the converter surface. Any H<sup>-</sup> ions formed at the surface will then be accelerated back across the sheath by the same potential. They pass through the plasma and the extraction slot and are focused geometrically at the entrance aperture of the mass spectrometer.

It has been shown that cesium coverage can reduce the work function of a metal surface and consequently enhance the yield of H $^+$  tons. 8.9 In this source, cesium was denosited on the converter surface by evaporating the metal directly into the plasma from two 10 cm long S.A.E.S. getter dispensers.



Fig. 2. The H<sup>-</sup> ion spectrometer signal as a function of extraction voltage V<sub>a</sub> at constant discharge power.

The amount of cesium introduced can be easily controlled by adjusting the heater current of the dispenser strips.

#### Experimental Results

The source was first operated without  $\underline{ce;ium}$  with a discharge voltage of 60 V and a discharge current of 3.5 A. Langmuir probe characteristics indicated that the plasma density was 6  $\times$   $10^{10}$  cm $^{-3}$  and the electron temperature was 1.5 eV when the plasma grid bias voltage  $V_{0}$  = 0.

When an acceleration potential  $V_a$  was applied to the source anode, a beam of HT ions together with a large quantity of electrons were extracted from the source. The mass spectrometer output signal shows a sharp HT ion peak as illustrated in Fig. 2. The height of this HT ion peak increased as the bias voltage  $V_a$  increased until the extraction becomes emission limited. These HT ions are not formed on the converter signal remained unaltered even when the converter was removed from the source.

The following measurement also proves that the H<sup>-</sup> ions are not coming directly from the source anode. The energy level diagram of Fig. 3 shows the relation between the energy of a H<sup>-</sup> ion and the potential of the source plasma by a volume process, then its energy  $E = eV_a - eV_p$  when it arrives at the detector. However, if the H<sup>-</sup> ion is generated by a desorption or a reflection process at the anode surface, then its energy E will range from a minimum of eV\_a to a maximum of eV\_a + eV\_p. In this multi-cusp source, the plasma potential V\_p can be varied by adjusting the plasma grid bias voltage V\_q. Figure 4 indicates that when V\_q is increased from 0 to +36 V, the plasma potential V\_p contact the energy from 0 to +36 V. The plasma potential V\_p is increased from 0 to +36 V. The plasma potential V\_p contact the plasma potential V\_p contact the plasma potential V\_p is increased from 0 to +36 V. The plasma potential V\_p contact V\_p cont



Fig. 3 Potential energy of the H<sup>-</sup> ion produced in the plasma or at the anode surface.

same time the spectrometer signals in Fig. 5 show that the H  $\,$  ion peak shifts to the low energy side by the same amount. This result demonstrates that the H  $\,$  ions observed in Fig. 2 are indeed produced in the bulk of the plasma.



Fig. 4. Langmuir probe characteristics obtained with two different plasma grid voltages.



Fig. 5. The energy spectrum of the H<sup>-</sup> ions for two different plasma grid bias voltages.

The amount of volume-produced H<sup>-</sup> ions that can be extracted from the source depends not only on the acceleration voltage  $V_a$ , but also on the source pressure. With a constant discharge power, Fig. 6 shows that the H<sup>-</sup> ion peak can increase substantially as the pressure is increased from 1  $\times$  10<sup>-6</sup> to 7  $\times$  10<sup>-6</sup> Torr.

cesium was introduced into the When hydrogen plasma and the converter is in place, nyarogen plasma and the converter is in plate, a second group of  $H^{-}$  ions with energy  $E = eV_{a} + eV_{c}$  appear in the spectrometer signal (Fig. 7). The characteristics of this second group of  $H^{-}$  ions can be summarized as follows: (1) The height of this second  $H^{-}$  ion peak increases as more and more cesium is added plasma. However, there is no to the appreciable change in the si volume-produced H<sup>+-</sup> ion peak. size of the (2) As the converter bias voltage  $V_{\rm C}$  is varied from 100 V to 300 V, the energy of this second group of H" ions changes accordingly as shown in Fig. 8 but the energy of the volume-produced Hions remains unchanged. (3) When the acceleration potential V<sub>a</sub> = 0, volume-produced H<sup>-</sup> ion peak disappears the and only the second group remains. In fact, these H<sup>-</sup> ions are now "self-extracted" from the source. The energy of this second group of



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Fig. 6. The H<sup>-</sup> ion spectrometer signal as a function of gas pressure at constant discharge power.

H<sup>-</sup> ions again changes with the converter bias voltage V<sub>C</sub> as illustrated in Fig. 9. On the basis of these results, one can conclude that the second group of higher energy H<sup>-</sup> ions are generated at the surface of the converter. A detailed study on the formation of these H<sup>-</sup> ions is presented in the next section. (4) Under the same cesium environment and discharge conditions, Figs. 8 and 9 also show that the amount of H<sup>-</sup> ions in the surface-generated group increases as V<sub>C</sub> is changed from 100 V to 200 V, and then decreases when V<sub>C</sub> is further increased to 300 V. A similar optimum converter voltage V<sub>C</sub> has also been found in the self-extraction negative ion source.10 It is suspected that the best cesium and Hydrogen coverage that favors the formation of H<sup>-</sup> ions may occur right at this optimum



Fig. 7. The energy spectrum of the H<sup>-</sup> ions when cesium is added to the discharge.



Fig. 8. The energy spectrum of the H<sup>-</sup> ions as a function of converter bias voltages at constant discharge power.

converter bias voltage. (5) The energy spectrum of the second group of H<sup>-</sup> ions has a steep rise at  $E = eV_C + eV_A$ , and then decays towards the higher energy side. This group of surface-generated H<sup>-</sup> ions therefore have a larger energy spread than the volume-produced ones.

Figure 7 shows that the surface-generated H<sup>-</sup> ion peak is about four times bigger than the volume peak. When the source is operated at a higher pressure and extraction voltage, the amount of H<sup>-</sup> ions produced by volume and surface processes are approximately equal (Fig. 8). However, when there is no cesium in the hydrogen discharge, the number of surface-generated H<sup>-</sup> ions will diminish by about two orders of magnitude.<sup>11</sup> The second H<sup>-</sup> ion peak in the spectrometer output signal will therefore be much smaller than the first peak.



## Fig. 9. The energy spectrum of the H $^-$ ions as a function of converter bias voltages at constant discharge power with $V_{\rm A}{=}0.$

It has been reported that there are two groups of H" ions in the energy spectrum of the negative ion beam extracted from a planotron<sup>12</sup> or a duoplasmatron.<sup>13</sup> In both types of sources, the low-energy peak corresponds approximately to the anode notential while the high-energy Deak corresponds to the cathode potential. The high-energy group appears only in the presence of cesium an is formed at the cathode surface of the planotron and at the tip of the center rod of the duoplasmatron. In both sources, the amount of H<sup>-</sup> ions in the low-energy group depend only on the hydrogen content. This low energy group is interpreted to be produced by resonant charge exchange of fast H" ion of the high-energy group with hydrogen atoms in the extraction gap of the planotron.<sup>12</sup> In the duoplasmatron however, it is believed that a volume process is responsible for the creation of the low-energy H<sup>+</sup> ions.<sup>13</sup> The results of the present experiment seem to confirm the latter interpretation.



Fig. 10. A circular converter with four different materials brazed on the four quadrants.

#### Converter Material Study

In order to investigate different converter materials for use with the self-extraction negative ion source, a rotating converter disk with four different materials brazed on the four quadrants was employed (fig. 10). This converter was installed in the multi-cusp ion source (fig. 1) equipped with one exit aperture so that only the negative ions generated by one portion of the converter disk woul exit from the source. The source was operated in the presence of cesium with  $V_a = 0$  and the converter was blased at -200 V with respect to the anode. The energy spectrum of the "self-extracted" H" ion beam was detected by the mass spectrometer. With this arrangement, the yield of H" ions for each metal could be converter potential.

Figures 11 - 13 show the energy spectrum of the H<sup>-</sup> ions produced by Mo, W, Pt, Ni, Cu, Re, Ta and Pd. The single of the spectrum differs from one material to the other. In general, two distinct groups of surfacegenerated H<sup>-</sup> ions can be identified. The energy of one group is approximately equal to the sheath potential, indicating that the ions leave the converter surface with little or no energy. These H<sup>-</sup> ions can be produced on the converter by a desorption process.8,<sup>14-17</sup>

The Hions can be desorbed from the converter when positive ions enter the surface layer provided the energy transferred in the collision is equal to or greater than the adsorption energy of hydrogen. In this case, the average energy gained by the H<sup>-</sup> ions is usually small, <sup>18</sup> and their final energy should be approximately equal to the sheath potential. The cross-section for hydrogen sputtering by hydrogen incident upon metallic hydrides is small.<sup>3</sup> However, this However, cross-section increases quite rapidly with the mass of the projectile.<sup>19</sup> In addition to reducing the surface work function, which is essential for the efficient production of  $H^{-}$  ions, the Cs<sup>+</sup> ions in the plasma could also serves as a sputtering agent to enhance the hydrogen desorption rate.





It has been found that the coefficient of secondary H<sup>-</sup> emission from a molybdenum surface exposed to  $Cs^+$  ion bombardment can be improved if the surface loading of hydrogen is performed in a plasma rather than in a gas atmosphere.<sup>17</sup> However, the degree of However, hydrogen adsorbed on a cesiated surface may depend on the substrate material. Perhaps this is the reason why the very low energy H<sup>-</sup> ion yield is typically higher for Mo and Re. Reflection of neutral atomic hydrogen with energy E > c -  $E_a$ , 20 where : is the surface work function and Ea is attachment energy of the H<sup>+</sup> is the electron attachment energy of the  ${\rm H}^-$  ion, may also lead to the formation of  ${\rm H}^-$  ions.  $^{21}$  The importance of this process will de, end upon the concentration and the energy distribution of atomic hydrogen in the source.



Fig. 12. The energy spectrum of the H<sup>-</sup> ions produced on Cu, Mo, Re and Ta at constant converter voltage.

The second group of H- ions have a higher energy and appear to be produced by a reflection process.<sup>20</sup> An incoming H<sup>+</sup> ion strikes the converter surface with energy E = 200 eV after falling through the sheath. The molecular species (H $_2$  and H $_3$ ) are fragmented to form atomic hydrogen particles with energy E/2  $\approx$  100 and E/3  $\approx$  6G eV respectively.<sup>22</sup> If the H<sup>-1</sup> ions are from the three converted groups of backscattered atomic hydrogen particles by capturing the additional electrons, then their average energy at the detector should be close to the limiting valves, 2E (= 400 eV), E + E/2 (= 300 eV), or E + E/3 (= 266 eV). In the presence of cesium, the species current distribution  $H^+$ :  $H^+_2$ :  $H^+_3$  = 7 : 33 : 60. Thus the dominant species is  $H^+_3$  and most of the  $H^-$  ions formed by reflection of positive hydrogen ions should have energy equal to or less than 266 eV which is illustrated by the energy spectra of Figs, 11-13. In case of Pd, the group of H" ions formed by the reflection of H<sup>±</sup> ions is distinguishable.



Fig. 13. The energy spectrum of the H<sup>-</sup> ions produced on Pd, Mo, W and Re at constant converter voltage.

The energy spectra of Fig. 11 also demonstrate that Pt produces the biggest number of H<sup>-</sup> ions formed by reflection. This result agrees with the Marlowe code calculation which shows that at a given energy, the fraction of reflected particles increases with the Z of target material.<sup>23</sup> Both No and Re give the highest total H<sup>-</sup> yield at optimum conditions with the majority of the H<sup>-</sup> ions belonging to the low energy group. Re is a better choice when used as a converter material because it has lower sputtering coefficient than No. In addition, its electron affinity for negative ion formation is lower than that of Mo.<sup>10</sup> Both elements give a maximum H<sup>-</sup> yield with a converter bias voltage of about 200 V.

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\*This work is supported by the Fusion Energy Division, U. S. Department of Energy, under contract W-7405-ENG-48.

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