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WORK FUNCTION DEPENDENCE OF SURFACE PRODUCED H^- IN THE PRESENCE OF A PLASMA

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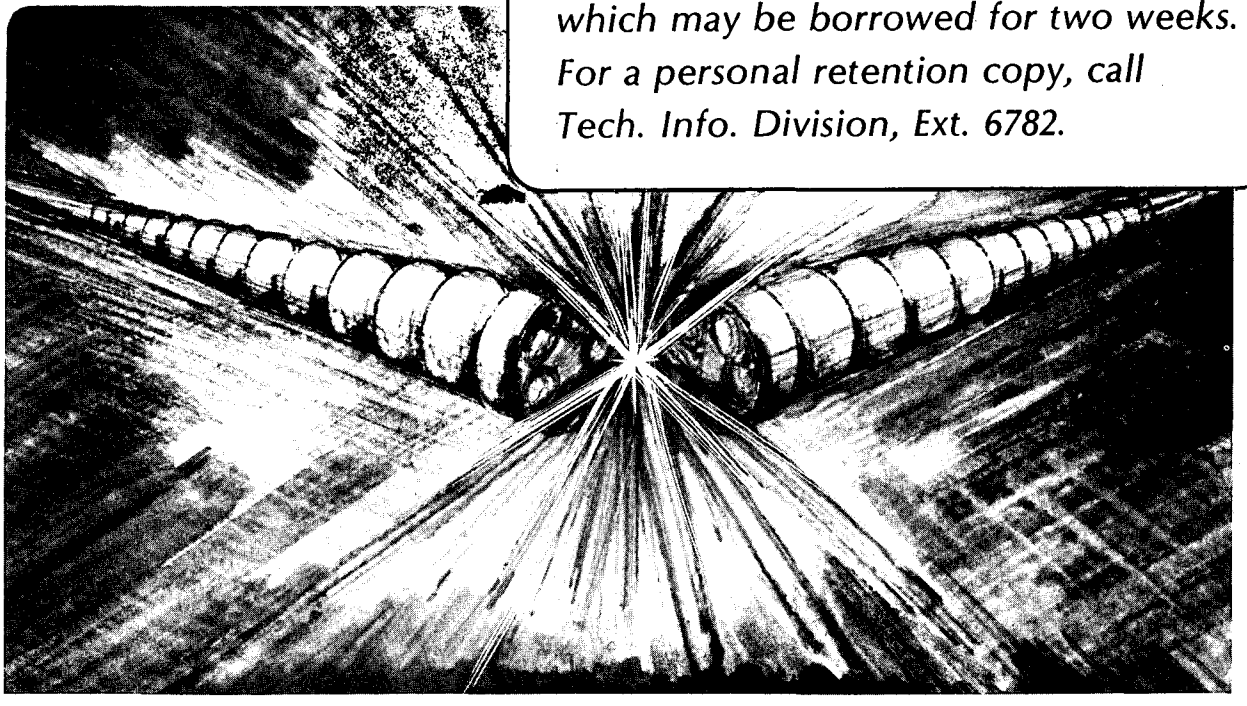

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WORK FUNCTION DEPENDENCE OF SURFACE PRODUCED H^- IN THE PRESENCE OF A PLASMA*

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ABSTRACT

The maximum H^- flux from a negatively biased "converter cathode" occurs at the work function minimum. A cesiated hydrogen plasma produces a partially-cesiated surface at the converter. The cesium coverage can be controlled by the cesium partial pressure, the bias on the converter and the plasma density, while the work function of the converter surface is measured by the photo-electric effect, using a bright light source and a series of filters. The angular dependence is measured by rotating the converter.

INTRODUCTION

A high-current negative-ion (H^-) beam can be produced by immersing a negatively biased "converter" surface in a cesiated hydrogen plasma[1]. The electric field from the plasma to the converter accelerates plasma ions to the surface. Some part of the flux is converted to H^- ions which are accelerated back across the sheath and can be extracted from a slit placed opposite the converter.[2] The population of Cs in the discharge controls the work function of the converter and the H^- current, which is greatest at the lowest work function value.

Leung and Ehlers measured the energy distribution of the H^- beam from their surface-plasma ion source and observed two distinct groups in the range from the bias potential to about twice that potential.[3] The higher energy components were further resolved and identified as backscattered ions from H^+, H_2^+ and H_3^+ bombardment on the converter, while the lowest energy portion was identified with collisionally desorbed H^-.[4]

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Leung and Ehlers found that their low energy component was substantially larger than the backscattered component. The ratio of the two major H^- components is very important to the H^- beam quality and the application of the source to an intense neutral beam system. This is because the higher energy (backscattered) portion also has a large angular distribution.

Hiskes[5] compared the backscattered and desorbed portions based on a theoretical model, and estimated the H^- production efficiency per incident hydrogen nucleus to be less than 1% through desorption, compared to some tens of percent by backscattering. Although Cs^+ ions in the plasma may enhance the desorption, backscattering seemed to be the dominant H^- production mechanism.[6]

The discrepancy might be explained by the difficulty in seeing all of the backscattered portion because of its large divergence.

This experiment was designed to measure the angular distribution as well as the energy distribution of H^- from the converter surface to help resolve the discrepancy.

EXPERIMENT

A schematic representation of the apparatus is shown in Fig. 1. A discharge between the filaments and the chamber walls

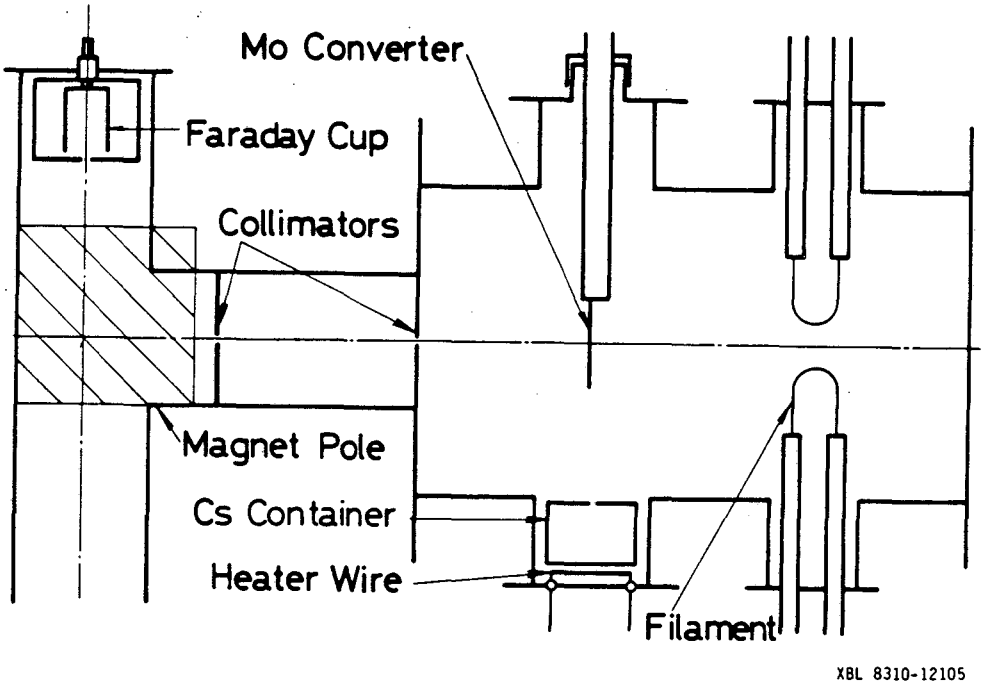

Fig. 1. Schematic of the apparatus showing the rotatable molybdenum converter for angular distribution measurements.

creates the plasma. A magnetic "bucket" geometry is created by six rows of samarium-cobalt permanent magnets placed around the 15 cm diameter chamber.[7] The filaments are maintained at -90 V with respect to the chamber walls and the discharge current is controlled by adjustments in the filament temperature as the H_2 gas and Cs vapor densities are varied. The hydrogen pressure is usually kept at ~ 1 mTorr while the Cs coverage on the Mo converter is increased by heating the Cs oven, which puts more Cs into the discharge. Once introduced, the Cs remains in the discharge with a long time constant. The rotatable converter is not cooled, so the Cs coverage is in dynamic equilibrium with the plasma and depends on plasma temperature, density, Cs fraction and bias on the converter.

The negative ions from the converter must traverse 7.5 cm of plasma before entering the first slit at the exit of the chamber. A second slit completes the collimation of the beam before it enters a small magnetic analyzer. A slitted Faraday cup at the focus of the analyzer is used to measure the partial current and provides a momentum resolution of about 1.5%.

Previous experiments[2-4] have established that the maximum H^- yield occurs when the surface work function is at a minimum. This corresponds, also, to a maximum yield in the low energy portion of the spectrum. Thus by monitoring the low energy H^- peak as Cs is introduced into the plasma, the minimum work function conditions can be found. Then, with small adjustments in the oven temperature and discharge parameters, the conditions can be stabilized so that the H^- yield is constant over several hours.

For the results reported here, the converter bias was maintained at -150 V. The plasma parameters were $n_e = 3 \times 10^{10}$ cm^{-3} and $T_e = 2.5$ eV, as measured with a small Langmuir probe.

The normal to the converter was initially aligned with the collimation to the analyzer. After the plasma had been stabilized, the analyzer magnet was swept and the H^- energy spectrum recorded. The converter was then rotated by 5° and the procedure repeated. This process continued until the converter had been rotated by 45°, and then repeated once more at the 0° position to confirm the constancy of the H^- yield which was generally within 2% of the original measurement. The entire proces required about 4 minutes to complete.

The angle could be set to about 0.5° while the collimation admitted ions over a range of about 1.40°. Repetition of the experiment while rotating the converter in the opposite direction gave essentially the same results.

A typical raw data result at 0°, with the Cs coverage near optimum is shown in Fig. 2. This result is very similar to ones measured by Leung and Ehlers.[3] Note the sharp rise at the lowest Hall probe values, and the shoulders at the larger Hall probe values. The width of the curve corresponds in energy with H^- ions originating at the surface with nearly zero-energy,

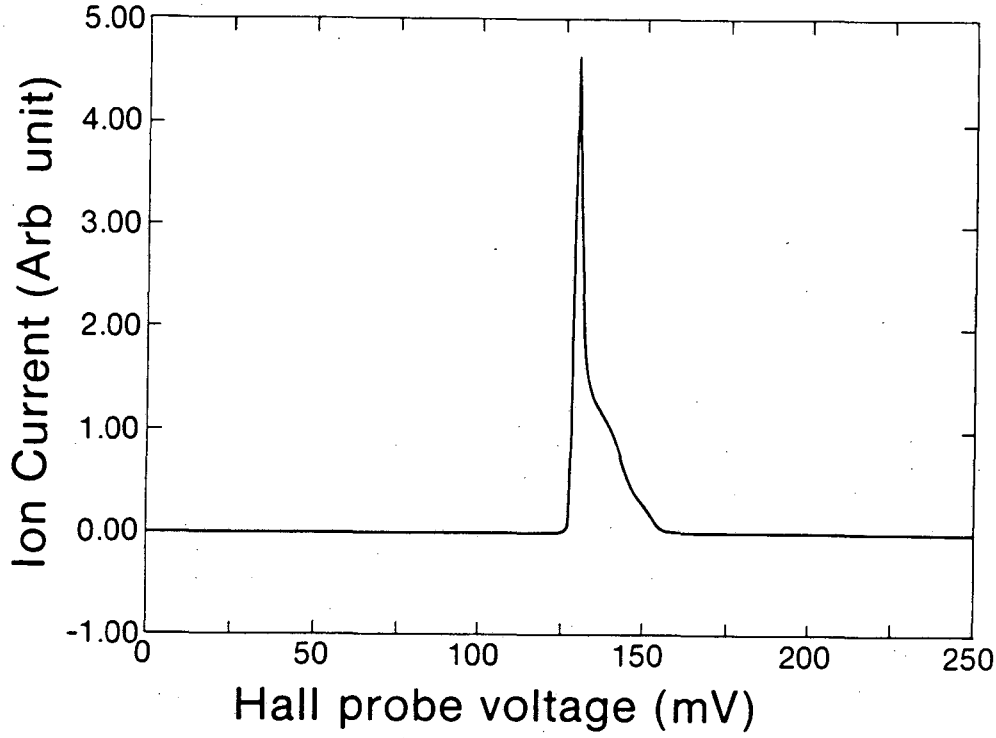

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Fig. 2. Raw unscaled data showing the H^- spectrum. No other spectra appear over the range normally swept.

to backscattered H^- ions from H_3^+, H_2^+ and some H^+ that had been accelerated to the converter across the sheath.

Figure 3 is a plot of relative H^- yield vs energy and angle of the converter. The energy scale has been normalized so that 100% corresponds to the bias on the converter (100% = 150 eV).

The minimum energy H^- ion that can be seen at each angle is governed by ions that are scattered parallel to the converter surface and then accelerated normal to the surface across the sheath. This leads to an expression for the minimum energy,

$$E_{min} = |V_c - V_p|(1 + \tan^2 \theta_0) \qquad (1)$$

where V_c and V_p are the converter and plasma potentials and θ_0 is the angle from the surface normal to the collimation line. We can use this equation as a check to see that no H^- that did not originate at the converter surface entered the analyzer. (e.g. H^- ions that originated elsewhere could be reflected from the sheath.)

If we now make a linear interpolation of the H^- yield at each energy from the 0° measurement to each succeeding angle measured and ending with I = 0 at θ_0 + 1.4°, then we can obtain the total relative H^- yield at each energy.

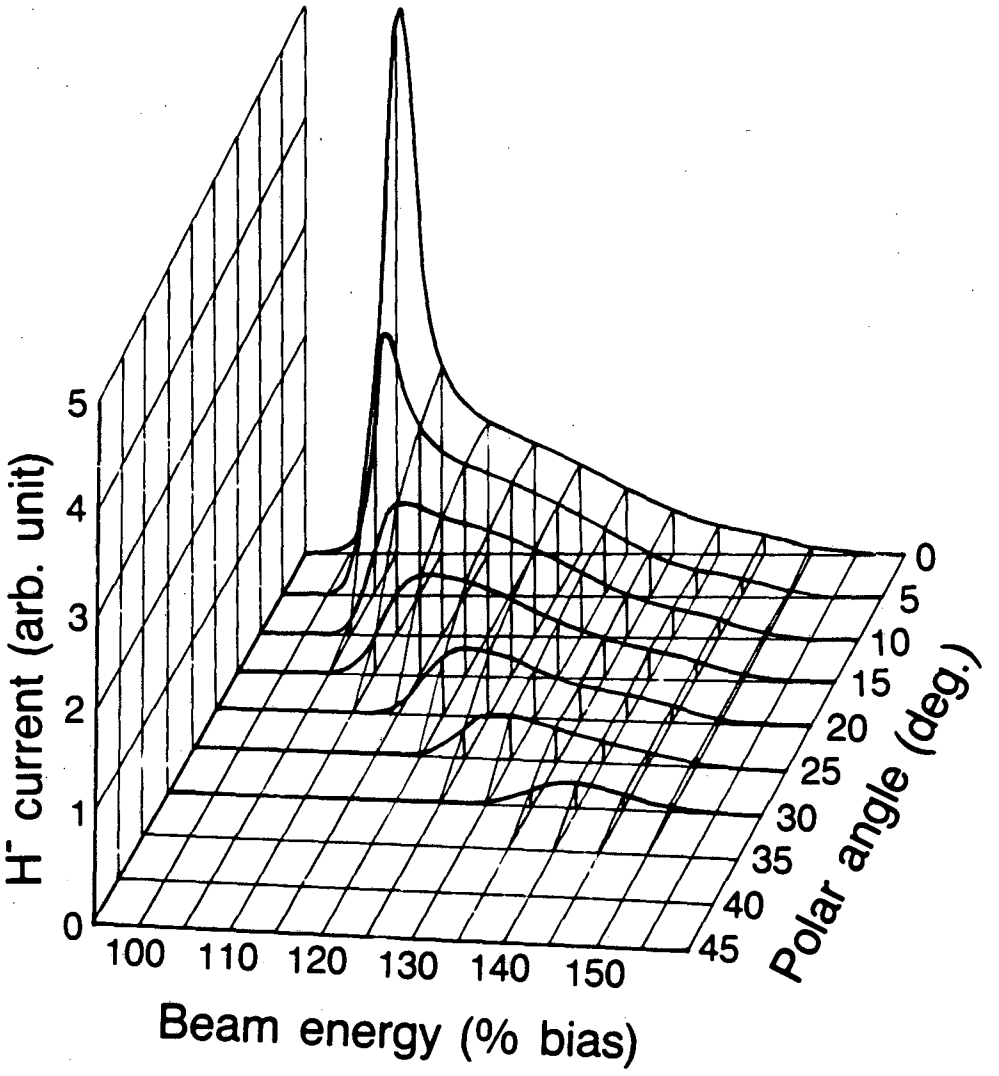

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Fig. 3. H^- spectra vs energy, scaled to the converter bias voltage (-150 V), for ten orientations of the converter in 5° steps.

The results of this calculation are shown in Fig. 4 where the total relative H^- yield is plotted vs normalized energy.

If we call the low energy component that part of the curve in Fig. 3 which lies between 100% and 115%, then it becomes apparent that most of the H^- yield comes from backscattered energetic hydrogen. The peak at ~130% corresponds to backscattering from

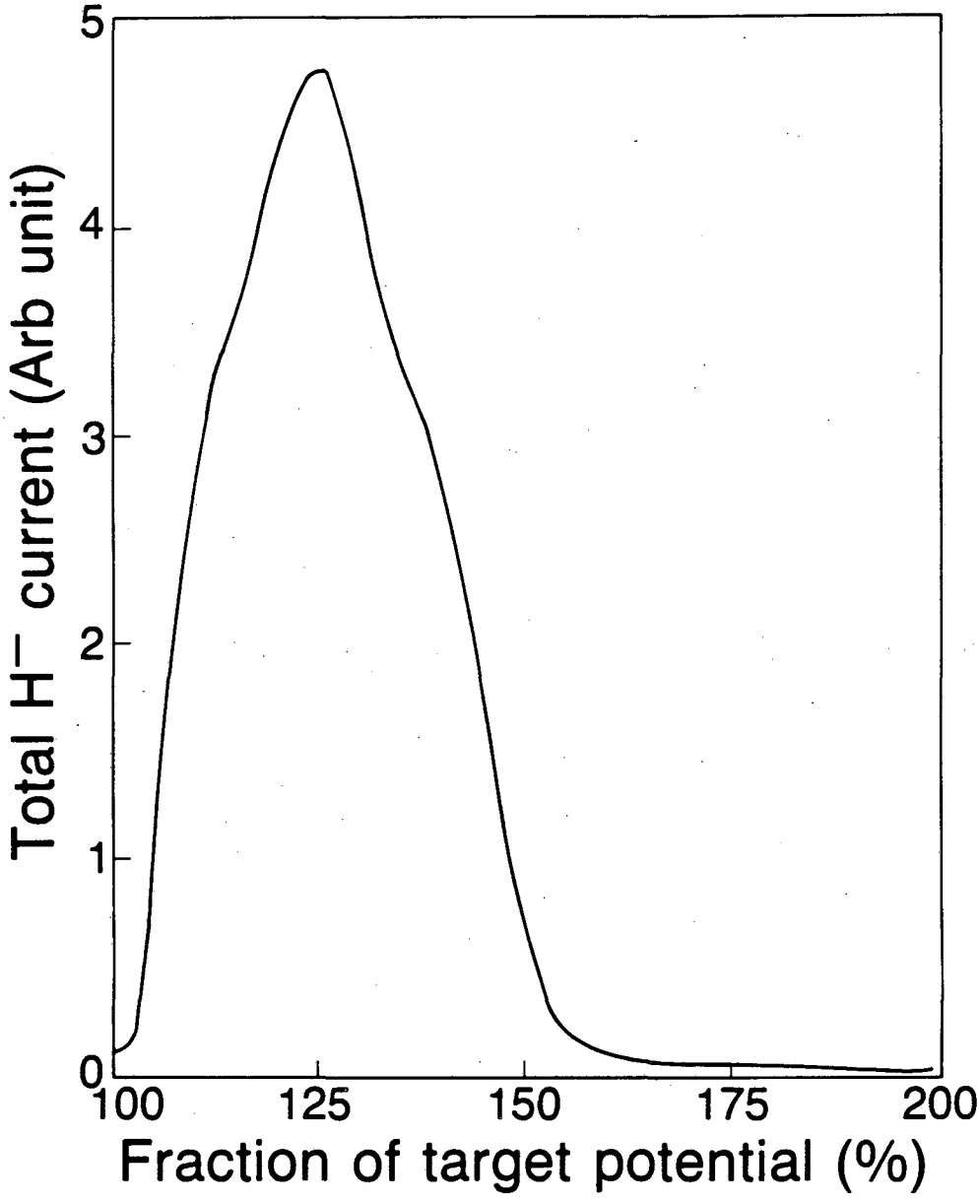

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Fig. 4. Integrated relative total H^- flux from the converter vs H^- energy scaled as in Fig. 3, using data shown in Fig. 3.

H_3^+. The sharp rise from ~155% to lower energies is accounted for by backscattering from H_2^+ while the small higher energy H^- yield is from H^+. The large amount of the molecular hydrogen-ion species in the discharge compared to H^+ is probably caused by the large cesium concentration necessary to maintain the minimum work function on the converter.

The converter, in this case, was made of polycrystalline molybdenum. It has been suggested[8] that lower work functions and better cesium adhesion might be obtained from monocrystalline surfaces. Work is now in progress to test this idea with several single crystal materials in various orientations.

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