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# Recent results on negative ion production and extraction from the Culham Ion Source Test Stand

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(Presented on 12 July 1989)

The plasma characteristics of a volume negative ion source are described. An indirect measurement of the negative ion current density in the source has been made. Beam extraction measurements are used to attempt to verify the measurement in the source. The two are found to be in proportion. The difference between the two is briefly discussed.

## INTRODUCTION

Negative ion beams are being considered for use in fusion plasmas, in defense, and in semiconductor processing. The volume source is a candidate for these applications because of its suitability for continuous operation. In this paper we report on the performance of a volume source in terms of both the plasma parameters and the extracted beam.

## I. THE SOURCE AND ACCELERATOR

The plasma generator, accelerator, and beamline used in this work have been described previously.<sup>1</sup> One feature of importance to this work is the fact that the area around the extraction electrode is insulated with respect to the beam-forming electrode. This together with two magnets in a quadrupole configuration in the beam-forming electrode form an electron suppressor. If the magnets are removed then the insulated insert when biased acts as a Langmuir probe. The beam current is measured in two ways. First, the current reaching the earth grid is measured (drain current), and this is the ion beam current plus leakage electrons from the electron trap plus some electrons due to stripping in the second gap of the accelerator, but these are counted as negative ions. These latter electrons if they escape are deflected out of the beam by a magnet outside the accelerator. The electron trap is efficient but some electrons are measured in the drain current. However, the trap efficiency can be calibrated either by an indirect method used previously,<sup>2</sup> or by

the use of helium in the discharge. Second, at a distance of 55.2 cm downstream of the accelerator, the ion current is measured using a beam transformer. The extraction experiments have been carried out with a 16-mm aperture.

## II. EXPERIMENTAL RESULTS

The plasma characteristics were measured for both hydrogen and deuterium. Positive ion current densities of the order of  $20 \text{ (mA/cm}^2\text{)}/(\text{W/cm}^3\text{)}$  were obtained with the source. To demonstrate the confinement properties of the source one can plot  $1/\text{current density}$  versus  $1/\text{pressure}$ . As shown by Green *et al.*<sup>3</sup> the slope of the linear portion of this curve is proportional to the reciprocal of the primary electron confinement time. Deviation from linearity at higher pressures is due to cross-field diffusion. Figure 1 shows the results. The source shows excellent confinement properties.

The electron temperatures as measured by the insert probe were less than 1.1 eV at the highest arc currents. Holmes *et al.*<sup>4</sup> show how a Langmuir probe may be used to measure the ratio of the negative and positive ion density  $n_-/n_+$  through the ratio of negative to positive current densities  $j_-/j_+$ . These are related by<sup>4</sup>

$$j_-/j_+ = k(1 - n_-/n_+), \quad (1)$$

where for hydrogen,  $k = 29.8$  and for deuterium,  $k = 42.1$ . By assuming that the drift velocity of positive and negative ions are equal we can hence obtain  $j_-$  knowing  $j_+$ . This assumption is fairly well supported by experimental evi-

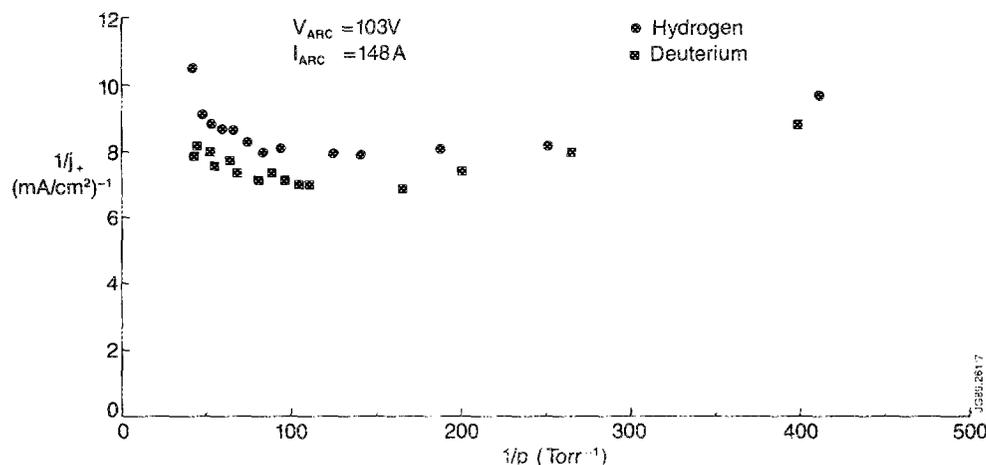


FIG. 1. Variation of  $1/\text{current density}$  with  $1/\text{pressure}$ .

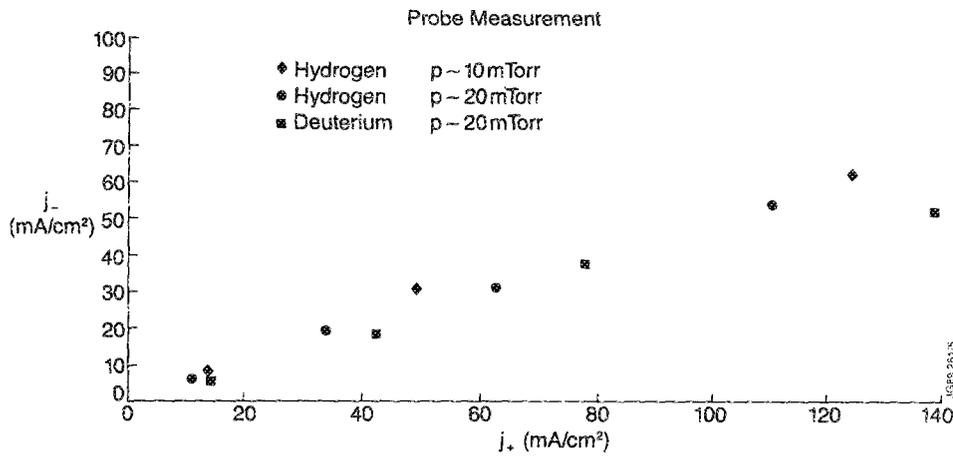


FIG. 2. Dependence of negative ion current density on positive ion current density.

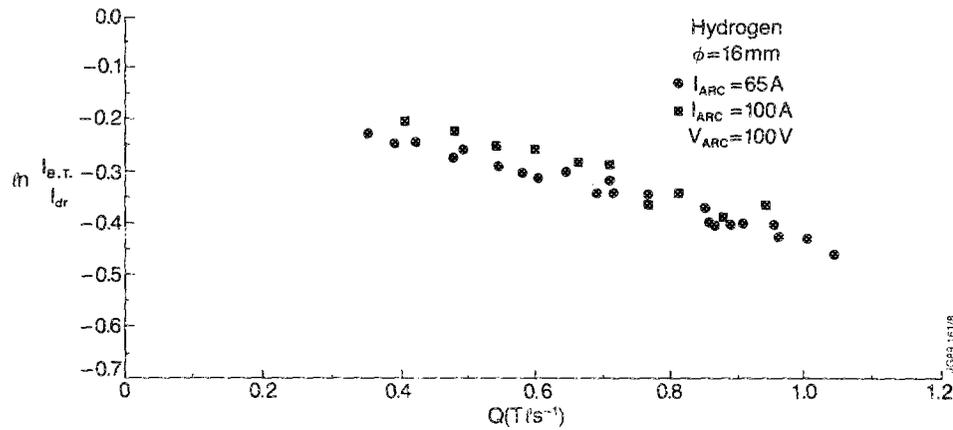


FIG. 3. Dependence of  $\ln(I_{BT}/I_{dr})$  on gas flow to source.

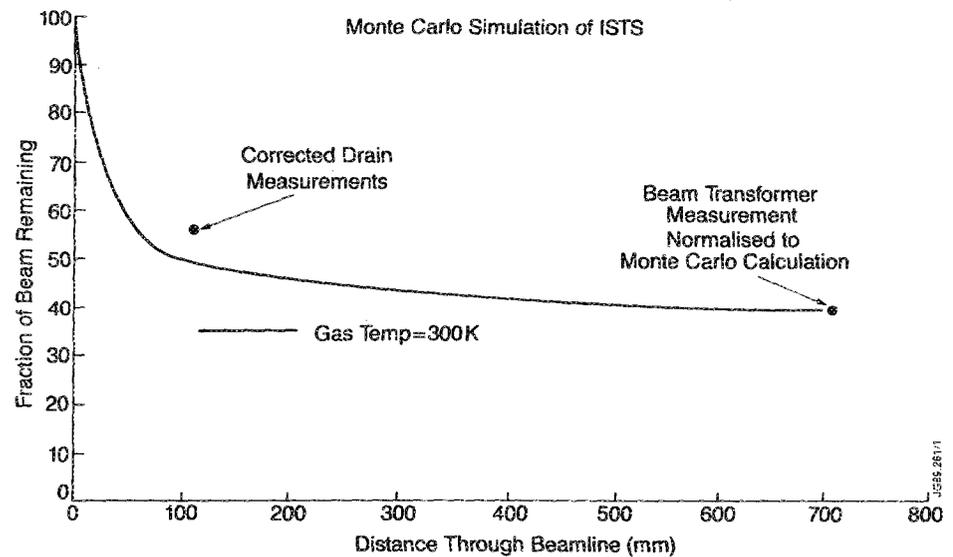


FIG. 4. Comparison between measured stripping and a Monte Carlo simulation.

dence.<sup>5,6</sup> In Fig. 2 we show the relationship between  $j_-$  and  $j_+$  in both hydrogen and deuterium. For hydrogen and deuterium the negative ion current densities are approximately equal at the same pressure. In fact, the value of  $j_-/j_+$  is lower in deuterium compared to hydrogen by about 20%. It is the increased value of  $j_+$  in deuterium which brings the current density up towards that in hydrogen.

We want to compare the extracted current density with that measured by the probe. However, it has been known for some time now<sup>1</sup> that stripping of the negative ions in the beamline due to gas from the source is a major limitation to measured performance. In order to show the extent of the problem we show in Fig. 3 the value of  $\ln(I_{BT}/I_{dr})$  against the gas flow to the source where  $I_{BT}$  is the current in the

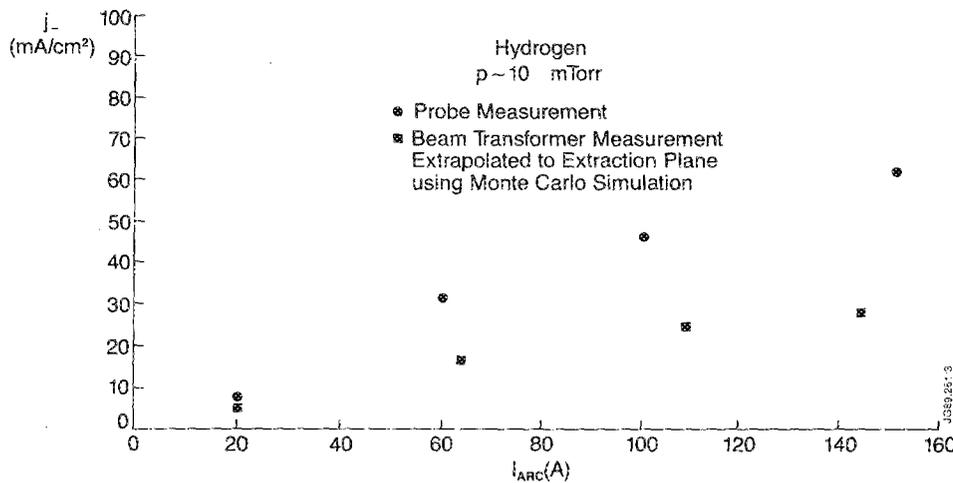


FIG. 5. Comparison between probe measurement of negative ion current density in the source and the measurement of the beam transformer current extrapolated to the extraction plane using the Monte Carlo simulation.

beam transformer at 55.2 cm from the exit of the earth electrode where the drain current  $I_{dr}$  corrected for the electron leakage is measured. This graph has two important implications. First, because of the dependence on gas flow it shows the existence of stripping between the electron trap electrode, the drain current being the current beyond this plane, and the beam transformer. Second, because the curve almost intercepts zero at zero gas flow it shows that the drain current is a good measure of the negative ion current. The discrepancy is a few percent and could be caused by an imprecise knowledge of the electrons leaking through the trap.

In order to try and model the situation we have used a two-dimensional Monte Carlo calculation to estimate the stripping through the beamline (no three-dimensional code was available to us) and Fig. 4 shows the results. The calculation underestimates the stripping. More realistically, the gas temperature leaving the source would be of the order of 700 K but then the agreement would be worse. In addition, since the source utilizes high fractions of vibrationally excited molecules, then the cross sections used in the stripping calculations which were for ground state  $H_2$  may be incorrect. Also, the gas dynamics may not be simply free molecular flow at least in the first extraction gap. To make a comparison with the probe results we have used the Monte Carlo calculations as a first approximation and calculated the current density leaving the source at the extraction plane by normalizing the beam transformer measurement to the simulation. Figure 5 shows the results. The ratio between the extrapolated current density at the extraction plane and the probe result is almost exactly a factor of 2. The probe measurement is at least a good qualitative measurement of the negative ion current density. An explanation for the discrepancy could lie in a number of areas. The Monte Carlo simulation certainly underestimates the stripping for the reasons given above. For it to be stripping alone implies that at the beam transformer only  $\sim 19\%$  of ions remain.

The probe actually measures  $n_-/n_+$  and to obtain  $j_-$  we have assumed that the drift velocities of positive and negative ions are equal. The results of Lea and Holmes,<sup>6</sup> who correct exactly for stripping, show that if the drift velocities are equal then the probe result is validated by the extraction experiment over a wide range of plasma parameters. An-

other possible factor is the presence of the magnets near the insert in extraction experiments. This field may reduce the negative ion density in the region of the extraction aperture.<sup>7</sup>

### III. DISCUSSION

The work in the report has described a volume source of  $H^-/D^-$  ions with good plasma characteristics. It is possible to correlate at least qualitatively the extracted beam current density with that inferred from a probe measurement. It is thought that stripping alone may not be sufficient to explain the discrepancy between the probe and beam measurement. There may be an effect due to the inequality of drift velocities for the negative and positive ions. However, it appears more likely that the use of a magnetic field to suppress electrons may lead to a reduction in the negative ion density available for extraction.

### ACKNOWLEDGMENT

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<sup>1</sup>R. McAdams, A. J. T. Holmes, A. F. Newman, and R. King, in *Proceedings of the 3rd European Workshop on Production and Application of Light Negative Ions*, Amersfoort, 1988, p. 15.

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<sup>3</sup>T. S. Green, C. Goble, M. Inman, and A. R. Martin, in *Proceedings of the 7th European Conference on Controlled Fusion Plasma Physics Lausanne, 1975*, p. 73.

<sup>4</sup>A. J. T. Holmes, L. M. Lea, A. F. Newman, and M. P. S. Nightingale, *Rev. Sci. Instrum.* **58**, 223 (1987).

<sup>5</sup>R. McAdams and A. J. T. Holmes, in *Proceedings on Microwave and Particle Beam Sources and Directed Energy Concepts*, Los Angeles, 1989, p. 1061.

<sup>6</sup>L. M. Lea and A. J. T. Holmes, Culham Laboratory (unpublished result).

<sup>7</sup>T. S. Green (private communication).