

Lawrence Berkeley National Laboratory

Recent Work

Title

EFFECT OF GAS MIXING ON H PRODUCTION IN A MULTICUSP SOURCE

Permalink

<https://escholarship.org/uc/item/7tz7d18r>

Authors

Leung, K.N.
Ehlers, K.W.
Pyle, R.V.

Publication Date

1985-05-01



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

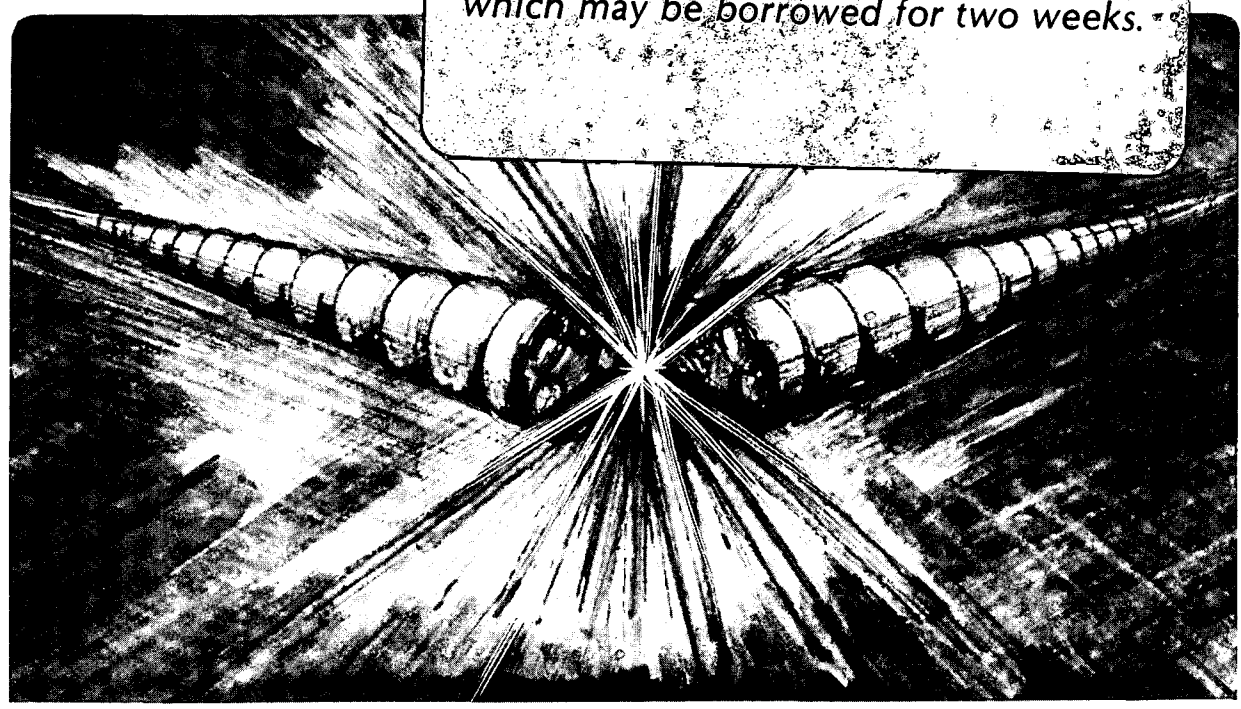
Submitted to Review of Scientific Instruments

EFFECT OF GAS MIXING ON H^- PRODUCTION
IN A MULTICUSP SOURCE

K.N. Leung, K.W. Ehlers and R.V. Pyle

May 1985

TWO-WEEK LOAN COPY
*This is a Library Circulating Copy
which may be borrowed for two weeks.*



LBL-19712
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Effect of Gas Mixing on H^- Production in a Multicusp Source***K. N. Leung, K. W. Ehlers and R. V. Pyle****Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720****May 1985****Abstract**

The effect of gas mixing on volume H^- production in a magnetically filtered multicusp source has been investigated. By applying the proper bias voltage on the plasma electrode, the addition of xenon or argon gases to a hydrogen discharge can enhance the H^- yield. This increase in H^- output is closely related to the increase in plasma electron density in the filter and extraction chamber regions.

* This work was supported by the Air Force Office of Scientific Research and by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

Introduction

H^- and D^- ions are required for generating efficient neutral beams with energies in excess of 150 keV.¹ Recently it has been demonstrated that volume-produced H^- ions, extracted from a magnetically filtered multicusp source, can provide high quality H^- beams with sufficient current density ($\sim 40 \text{ mA/cm}^2$) to be useful for both neutral beam heating of fusion plasmas and accelerator applications.² In order to produce this high H^- current density, it was necessary to operate the prototype source with a discharge current as high as 350 A. Several schemes to improve the efficiency of the filter equipped H^- source have been investigated. By optimizing the extraction chamber length, a factor of 6 improvement in the H^- output has been achieved.³ Experimental results also indicate that the H^- yield can be enhanced by proper selection of the chamber wall material. When the source is operated with a low pressure hydrogen discharge, aluminum and copper chambers generally produce the highest H^- ion current.⁴ In this paper, we demonstrate that the extractable H^- current from the filtered multicusp source can be further improved by mixing hydrogen with other inert gases such as argon and xenon. In this case, the increase in H^- yield is found to be closely related to an increase in plasma electron densities in the filter and extraction chamber regions.

I. Experimental Setup

A schematic diagram of the apparatus is shown in Fig. 1. The stainless steel source chamber (20 cm diam by 24 cm long) is surrounded externally by 10 columns of samarium-cobalt magnets which form a longitudinal line-cusp configuration for primary electron and plasma confinement.⁵ These magnet columns are connected at the end flange by four extra rows of magnets. A

samarium-cobalt magnet filter⁶ divides the entire chamber into an arc discharge and an extraction region. This filter provides a limited region of transverse magnetic field which is strong enough to prevent the energetic primary electrons from entering the extraction zone. However, both positive and negative ions, together with cold electrons are able to penetrate the filter and they form a plasma in the extraction region.

The open end of the source chamber is enclosed by a two-electrode acceleration system. Positive or negative ions were extracted from the source through a small $0.1 \times 1.0 \text{ cm}^2$ slot. In order to optimize the H^- ion output, the first acceleration (or plasma) electrode was biased at a potential equal to, or more positive than the anode.⁶ Both hydrogen and the inert gases could be introduced simultaneously into the source chamber. The source pressure was measured by an ionization gauge. A steady-state plasma was produced by primary electrons emitted from two 0.05-cm-diam tungsten filaments. The entire chamber wall, together with the filter rods, served as the anode for the discharge.

Plasma parameters were obtained by small planar Langmuir probes located at the center of the source and extraction chambers. A compact magnetic-deflection mass spectrometer,⁷ located just outside the extractor was used for relative measurement of the extracted H^- ions as well as for the analysis of the positive ion species. A dc discharge of 80 V, 3 A was employed throughout the experiment to generate a plasma density of 10^{11} cm^{-3} .

II. Experimental Results

(a) Source operation with hydrogen

The characteristics of the filtered source when it is operated with a pure hydrogen discharge have been investigated in previous experiments.^{2,3,6} In

order to maximize the H^- output current, it is essential to optimize both the source pressure and the bias potential of the plasma electrode with respect to the anode wall. The data shown in Fig. 2 or 3 illustrate that the best H^- yield for hydrogen gas only occurs at a source pressure of approximately 8×10^{-4} Torr (gauge reading). At this optimum pressure, the spectrometer signal for the H^- ions is the highest when the bias potential V_b on the plasma electrode is approximately 2.7 V as shown in Fig. 4. With this small positive bias, there is a factor of nearly 3 drop in density from the source to the extraction chamber (Table I). However, the difference in potential between the biased plasma electrode and the potential of the plasma in the extraction chamber is reduced from 2.6 V (for $V_b = 0$) to about 1 V (for $V_b = 2.7$ V). Because of this reduction in potential gradient along with the presence of only cold plasma electrons ($T_e \approx 0.7$ eV) in the filter and the extraction chamber, more H^- ions are now available for extraction. At this point, a further increase in the H^- ion output can be achieved either by increasing the discharge power or by injecting additional low energy electrons into the extraction chamber or filter region.^{2,8} Both these schemes increase the density of cold plasma electrons and therefore the production rate of H^- ions. The following sections demonstrate that such conditions can be obtained alternately by operating the source with a mixture of hydrogen and other inert gases.

(b) Source operation with hydrogen and xenon

The effect on the H^- yield by adding xenon gas into the hydrogen discharge is illustrated in Fig. 2. The source was initially operated with only pure hydrogen. As xenon gas was introduced into the discharge, and with the bias potential V_b on the plasma electrode optimized, the H^- output

first increased, reached a maximum, and then decreased as the pressure was increased. The data in Fig. 2 also show that the highest H^- output occurs at a total pressure of 1.5×10^{-3} Torr when xenon is added to the optimum hydrogen base pressure of 8×10^{-4} Torr. At this point, the increase in H^- yield is more than 75% for a constant discharge power of 80 V, 3 A. If the ionization gauge readings on the source pressure are corrected for hydrogen (correction factor = 2.4) and xenon (correction factor = 0.37), then the real increase in pressure due to the addition of xenon gas is just 13%.

Figure 4 shows the spectrometer output signal for the H^- ions as a function of the bias potential on the plasma electrode. With the source operating in pure hydrogen, the optimum bias voltage is approximately 2.7 V. When xenon is added to the hydrogen discharge, the optimum bias voltage is increased to about 5.5 V. A higher bias voltage is required because the potential of the plasma has increased and thus the difference in potential between the plasma electrode and the plasma in the extraction chamber is larger (3.5 V when $V_b = 0$). At the optimum bias voltage, Table I shows that the plasma density in the source and extraction chamber has increased by 100 and 83% respectively when the total pressure is adjusted to 1.5×10^{-3} Torr. There is almost no change in the electron temperature, but the plasma potential becomes more positive in both chambers.

When a positive ion beam is extracted from the source, the mass spectrum shows that the hydrogen ion species composition $H^+ : H_2^+ : H_3^+$ changes from 31:5:64 to 65:7:28 when xenon is added to the discharge. A large portion of the positive ion beam is now probably made up of xenon ions as they can cross the filter much easier than the hydrogen ions. These massive xenon ions bring cold electrons into the extraction chamber and they are effective in

enhancing the formation of H^- ions. In fact, the data in Fig. 2 and Table I demonstrate that the percentage increase in H^- yield is almost equal to the percentage increase in plasma electron density in the extraction chamber. If the added xenon gas pressure exceeds the optimum value, the discharge becomes too enriched with xenon ions and the H^- output decreases (Fig. 2), apparently due to the reduction in the number of either the molecular H_2^+ and H_3^+ ions or vibrationally excited H_2 molecules which are needed for the production of H^- ions⁹⁻¹¹ in addition to low energy electrons.

(c) Source operation with hydrogen and argon

Source operation with a mixture of hydrogen and argon has also been investigated and Figure 3 shows that the H^- yield can also be improved by adding argon to the hydrogen discharge. As in the case of xenon, there exists an optimum total pressure for each hydrogen base pressure. For a constant discharge power of 80 V, 3 A, the highest H^- output occurs at a total pressure of about 1.4×10^{-3} Torr. In this case, the increase in H^- yield is ~ 17% which is about the same percentage increase (~ 18%) in the plasma electron density in the extraction chamber. However, the data presented in Table I show that the increase in plasma density in the source chamber is 60%. The smaller increase in density in the extraction chamber is due to the fact that the argon ions do not leak through the filter as easily as the xenon ions. The optimum bias voltage for the plasma electrode occurs at about 4 V.

This technique of H^- enhancement should also be applicable to other inert gases such as He, Ne and Kr which do not generate impurity negative ions. However, the results of this study indicate that a larger improvement in the H^- yield is obtained by using the more massive gases. In this respect, the addition of cesium vapor to the hydrogen discharge in a filtered

multicusp source could be expected to produce similar results.¹² We were unable to test the possible effects of adding cesium to the hydrogen discharge because the source chamber was not designed to operate at the elevated temperature required to obtain the optimum cesium vapor pressure. But as the presence of cesium can cause voltage breakdown in the accelerator column, xenon gas becomes a better candidate for this application.

Acknowledgment

We would like to thank D. Moussa and D. Kippenhan for technical assistance.

This work was supported by the Air Force Office of Scientific Research and by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

Figure Captions

- Fig. 1 A schematic diagram of the ion source.
- Fig. 2 The H^- yield as a function of total hydrogen and xenon pressure for three different hydrogen base pressures (indicated by \blacktriangle \bullet \blacksquare).
The discharge is maintained at 80 V, 3 A.
- Fig. 3 The H^- yield as a function of total hydrogen and argon pressure for three different hydrogen base pressures (indicated by \blacktriangle \bullet \blacksquare).
The discharge is maintained at 80 V, 3 A.
- Fig. 4 The H^- output as a function of the bias voltage on the plasma electrode when the source is operated with an optimized pure hydrogen pressure of 8×10^{-4} Torr and with an optimized total hydrogen and xenon pressure of 1.5×10^{-3} torr.

References

1. K. H. Berkner, R. V. Pyle, and J. W. Stearns, Nucl. Fusion 15, 249 (1975).
2. R. L. York, Ralph R. Stevens, Jr., K. N. Leung, and K. W. Ehlers, Rev. Sci. Instrum., 55, 681 (1984).
3. K. N. Leung, K. W. Ehlers, and R. V. Pyle, Rev. Sci. Instrum., 56, 364 (1985).
4. K. N. Leung, K. W. Ehlers, and R. V. Pyle, Appl. Phys. Lett., (accepted for publication).
5. K. N. Leung, T. K. Samec, and A. Lamm, Phys. Lett. A 51, 490 (1975).
6. K. N. Leung, K. W. Ehlers and M. Bacal, Rev. Sci. Instrum., Rev. Sci. Instrum., 54, 56 (1983).
7. K. W. Ehlers, K. N. Leung and M. D. Williams, Rev. Sci. Instrum., 50, 1031 (1979).
8. K. N. Leung, K. W. Ehlers and R. V. Pyle, Lawrence Berkeley Lab. Report LBL-19253 (March, 1985).
9. B. Peart and K. T. Dolder, J. Phys. B 8, 1570 (1975).
10. B. Peart, R. A. Forrest, and K. Dolder, J. Phys. B 12, 3441 (1979).
11. J. R. Hiskes, A. M. Karo, M. Bacal, A. M. Breneteau, and W. G. Graham, J. Appl. Phys. 53, 3469 (1982).
12. S. P. Antipov, L. I. Elizarov, M. I. Martynov, and V. M. Chesnokov, Pribory I Tekhnika Eksperimenta, No. 4, p.42 (Moscow, 1984).

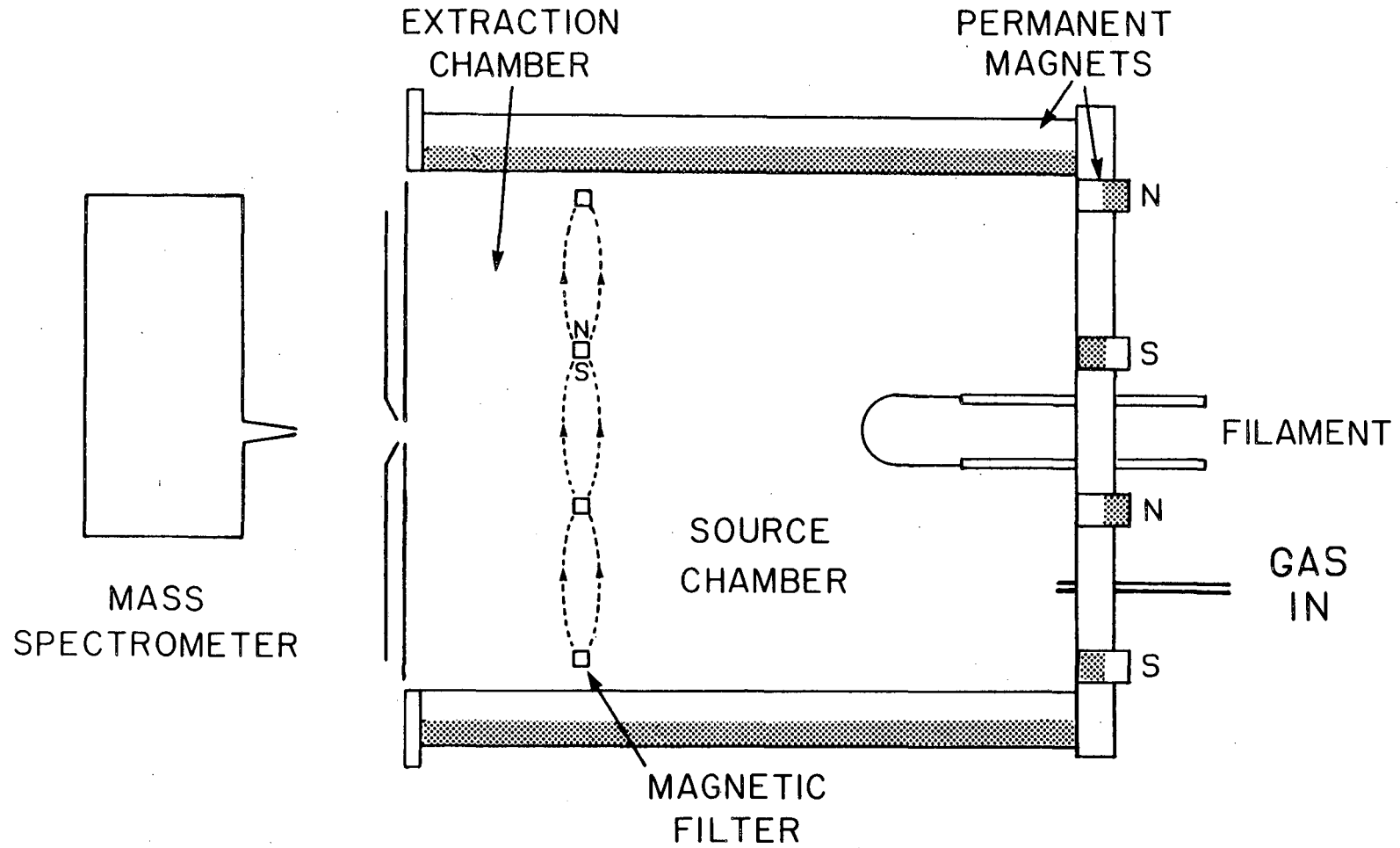
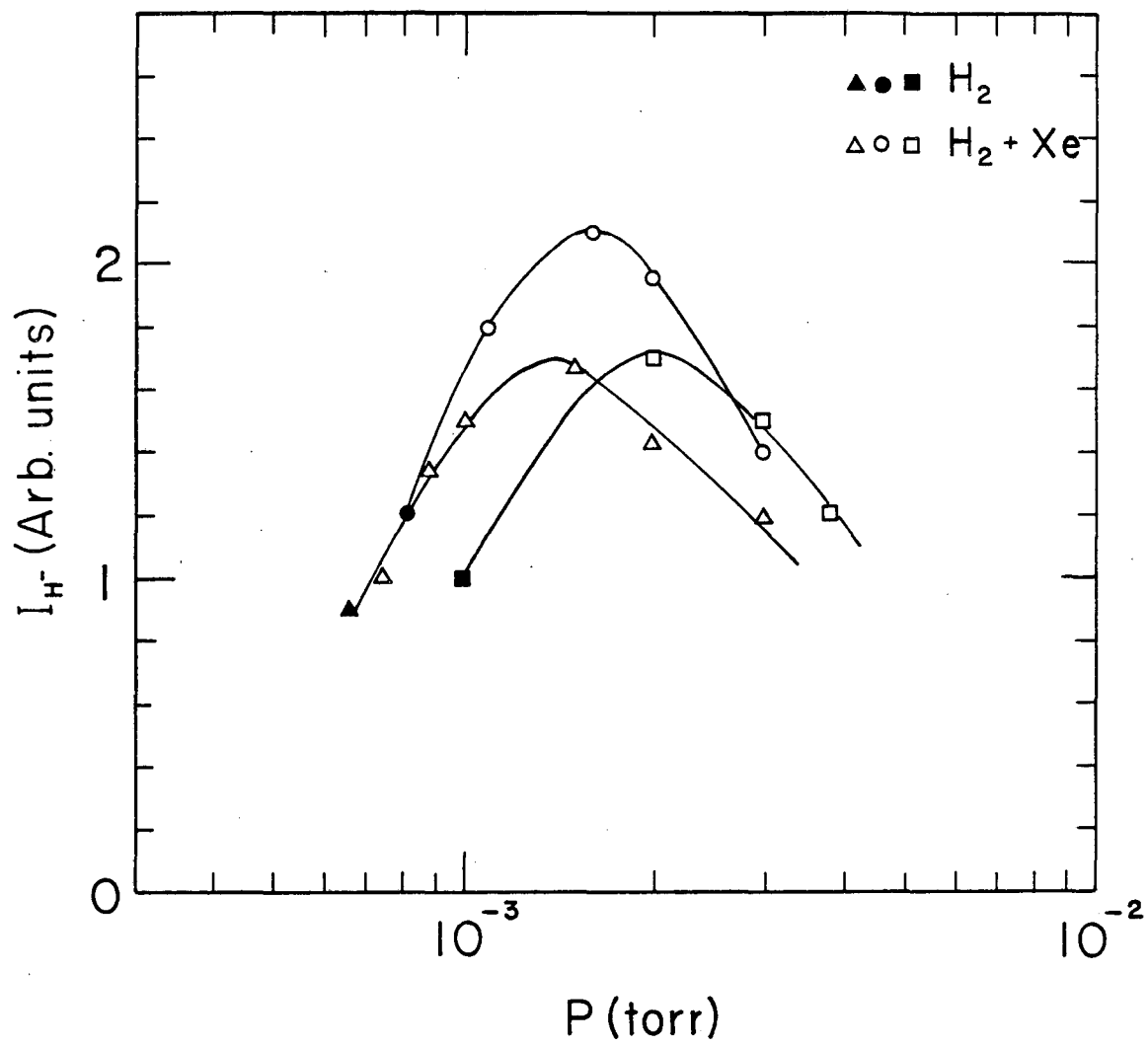


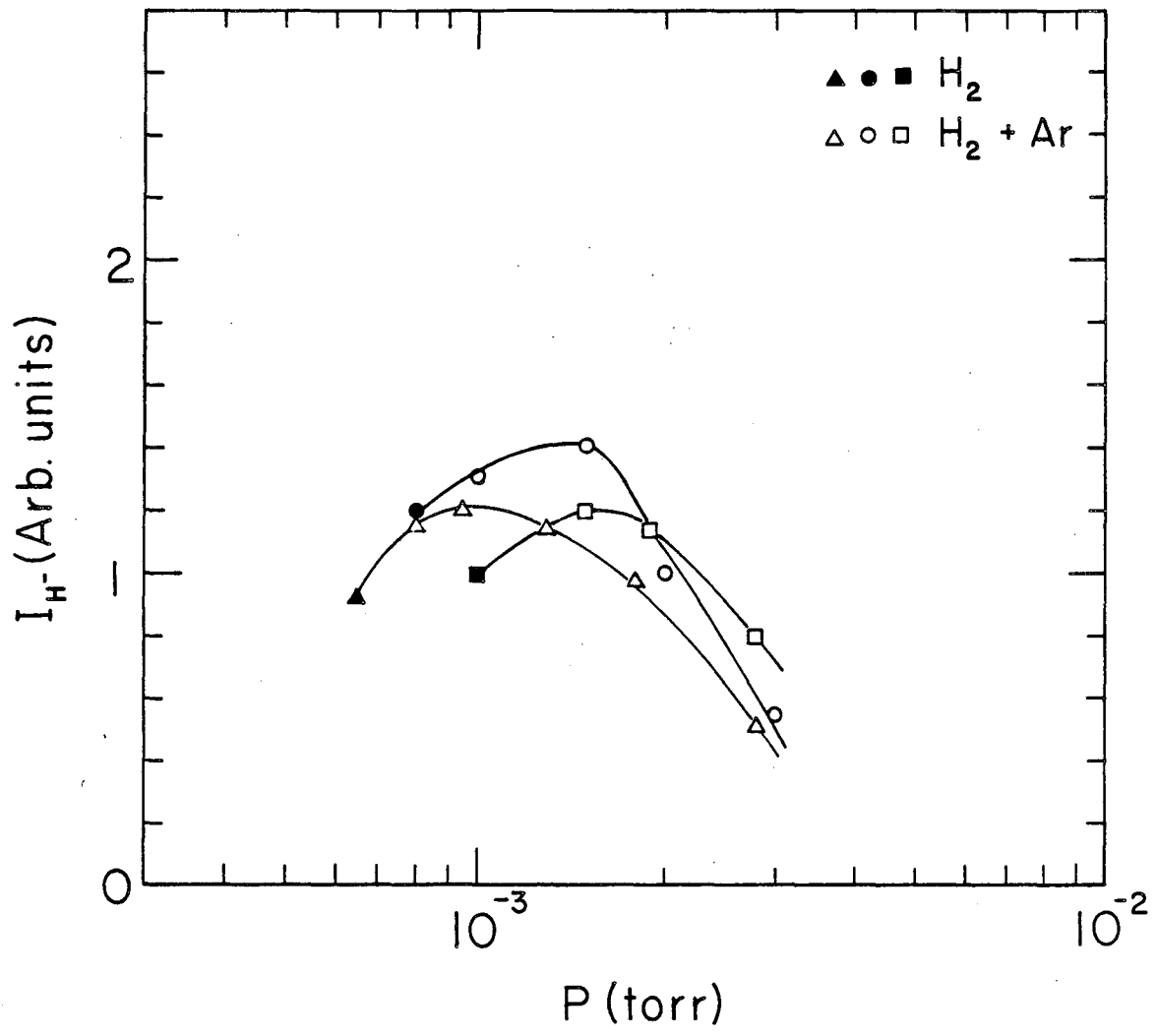
Fig. 1

XBL 847-2898B



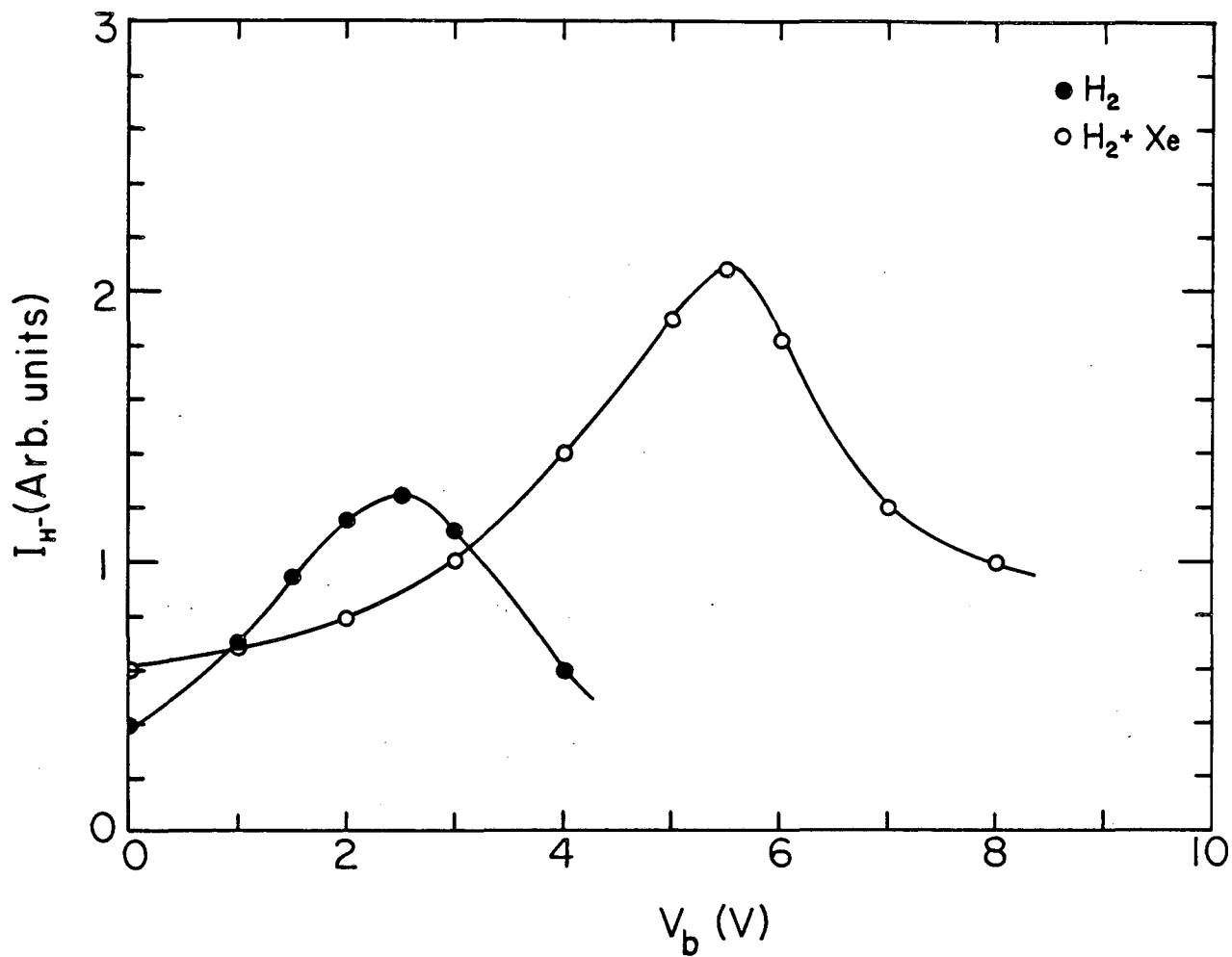
XBL 854-2258

Fig. 2



XBL 854-2257

Fig. 3



XBL 854-2259

Fig. 4

Table I. Plasma parameters obtained by Langmuir probes for a discharge power of 80 V, 3 A.

gas	gauge pressure	V_b (V)	chamber	n (cm ⁻³)	T_e (eV)	V_p (V)
H ₂	8 x 10 ⁻⁴ Torr	+2.7	source	2.5 x 10 ¹¹	2.1	5
			extraction	9.3 x 10 ¹⁰	0.7	3.8
H ₂ + Ar	1.4 x 10 ⁻³ Torr	+4	source	4 x 10 ¹¹	2.0	6.2
			extraction	1.1 x 10 ¹¹	0.75	5.0
H ₂ + Xe	1.5 x 10 ⁻³ Torr	+5.5	source	5 x 10 ¹¹	2.1	7.3
			extraction	1.7 x 10 ¹¹	0.75	6.4

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

*LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720*