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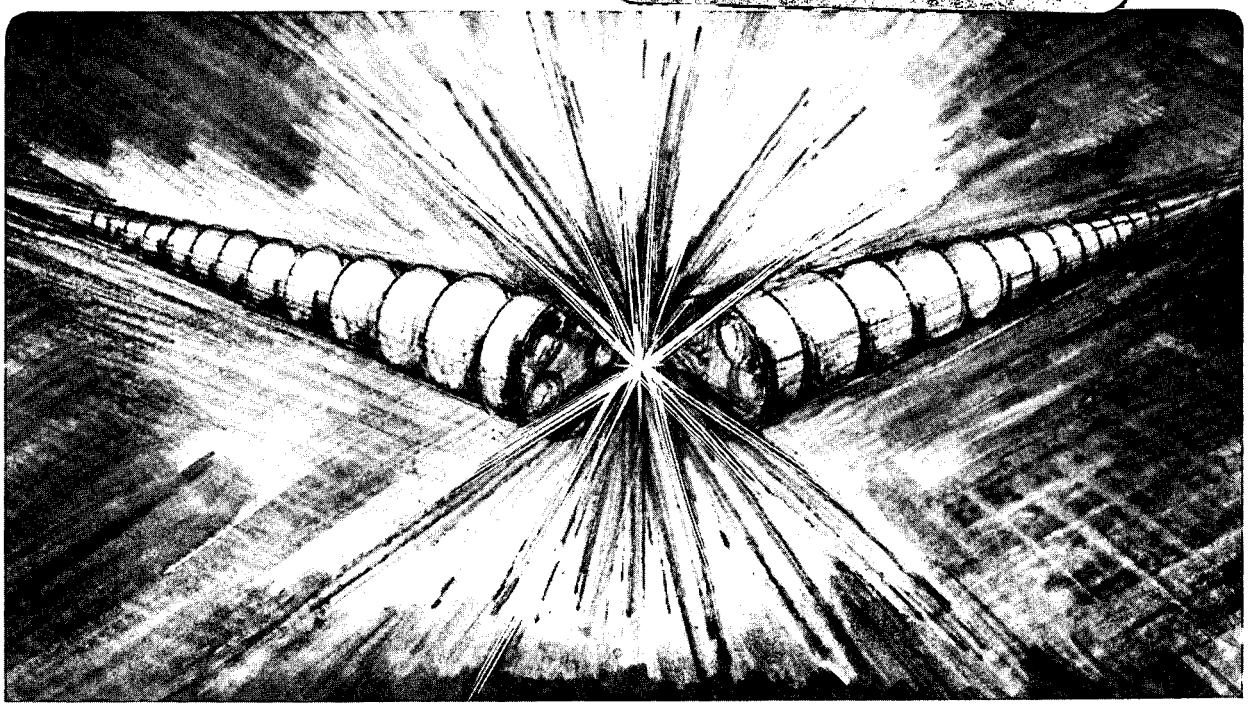

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LBL-18596

Optimization of H^- Production in a Magnetically Filtered Multicusp Source

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Abstract

Different techniques to increase the H^- yield in a multicusp source have been investigated. It is shown that the extracted H^- current can be enhanced by optimizing the discharge voltage, the neutral gas pressure, or by employing a magneto-electrostatic containment scheme. A factor of six increase in H^- output has been achieved by placing the extractor very close to the magnetic filter. It is also found that the extracted electron current is much reduced at this optimum geometry.

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Introduction

H^- and D^- ions are required in order to generate atomic 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 (~40 mA/cm^2) to be useful for both neutral beam and accelerator applications.[2] In order to produce such a high H^- current density, it was necessary to operate the prototype source with a discharge current as high as 350 A. For long pulse or dc operations, it is desirable to improve this relatively low arc efficiency so as to reduce source cooling requirements and to prolong cathode lifetime.

In this paper, several schemes to improve the efficiency of the filter equipped H^- source are described. The biggest improvement (~ a factor of six) is observed when the extractor is moved from the edge of the source towards the plane of the filter, thereby reducing the extraction chamber length. It is also found that the extracted electron current is much reduced at this optimum extraction position. This result suggests that the majority of the H^- ions extracted may be formed in the filter region. Further investigation is planned to determine the H^- density profile, how the H^- current scales with arc power, and the exact process of how the H^- ions are being formed.

I. Apparatus

A schematic diagram of the magnetically filtered multicusp ion source is shown in Fig. 1. The source chamber (20 cm diam by 18 cm long) is surrounded externally by ten columns of samarium-cobalt magnets to form a longitudinal

linecusp configuration for primary electron and plasma confinement. The magnet columns on the chamber wall are connected at the end flange by four extra rows of magnets which are also arranged in the linecusp configuration. A samarium-cobalt magnet filter[3] 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 all energetic primary electrons in the source chamber entering the extraction zone. However, both positive and negative ions, together with cold electrons, can penetrate the filter and form a plasma in the extraction region.

The open end of the chamber is enclosed by a two-electrode acceleration system. The first, or plasma electrode, has a small (0.15×1.3 cm^2) extraction slot and this electrode is biased at a potential equal to or more positive than the anode. A steady-state hydrogen plasma is produced by primary electrons emitted from two 0.05-cm-diam tungsten filaments. The entire chamber wall, together with the filter rods serve as the anode for the discharge. In normal operation, the presure outside the source was maintained at 1×10^{-4} Torr. The actual pressure inside the source chamber was approximately 1.5×10^{-3} Torr. Plasma parameters were obtained by Langmuir probes located at the center of the source chamber and in front of the plasma electrode in the extraction chamber.

A compact magnetic-deflection mass spectrometer,[4] located just downstream from the extractor was employed for relative measurement of the extracted H^- ions and for the analysis of the positive ion species. In addition, a permanent-magnet mass separator[3] was used with a Faraday cup to measure the extract H^- and electron current. With this apparatus, it was possible to measure the ratio of extracted H^- ion current to electron current

as well as the extracted H^- ion current density for different operational conditions.

In order to determine the optimum H^- yield as a function of the length of the extraction or source chamber, a moveable filter, a moveable extraction and spectrometer system, and a moveable end flange with permanent magnets attached to it were fabricated. With this arrangement, it was possible to adjust the position of the filter or to alter the extraction or source chamber length while the source was operating.

II. Experimental Results

(a) Optimization of the discharge voltage

The dependence of the extracted H^- ion current on the arc discharge voltage V_d was investigated for the case of the strong samarium-cobalt magnet filter ($B_{max} \approx 70$ G). With the plasma electrode biased at anode potential, and for a constant discharge current of 5 A, Fig. 2 shows that the extracted H^- ion current (as indicated by the mass spectrometer signal) increases almost linearly as the discharge voltage is varied from 40 V to 100 V. Above 120 V, the H^- ion current levels off and remains essentially constant for discharge voltages as high as 160 V. Thus, the H^- ion yield increases by approximately 40% as V_d is changed from 80 V to 120 V. When the power supply polarities were reversed for positive ion extraction, the positive hydrogen ion current also increased in the same manner as the H^- ion current when the discharge voltage was varied (Fig. 2). These data shows that the increase in H^- ion yield for the higher discharge voltages is primarily due to the increase in plasma production in the source chamber.

Once emitted from the filament, the primary electrons can either escape to the anode wall or perform ionization and other collisional processes. In

general, the higher the energy, the more ion-electron pairs will be generated by a single electron via multiple ionization. However, the loss rate of primary electrons to the chamber walls also increases with electron energy.[5] For a given source geometry, gas pressure and discharge current, there always exists an optimum discharge voltage that results in the highest source plasma density. Without the filter, the optimum discharge voltage for this source occurs at 80 V. With the inclusion of the filter, the source chamber is completely surrounded by permanent magnets and therefore the confinement time of high energy electrons is much improved. As a result, the optimum discharge voltage increases to > 120 V.

(b) Using a magneto-electrostatic containment scheme

By including a magnetic filter, the source chamber becomes essentially a "complete" multicusp generator. Hence, the plasma potential distribution in the source chamber is uniform both in the radial and axial directions.[6] The axial uniform plasma potential profile extends to the extraction chamber if a positive bias voltage is applied to the plasma electrode.[3,7] Thus, positive ions at the center of the source chamber will no longer "free-fall" toward this electrode as they do in the case of normal positive ion source operation. However, there will be a substantial loss of ions to the side walls due to an increased positive plasma potential in the source chamber.[6]

In a previous experiment, we demonstrated that the loss of positive ions to regions between the line-cusps can be reduced by installing strip-electrodes in between magnet columns.[8] When these electrodes are biased more positive than the plasma potential, they reflect positive ions back into the plasma volume, resulting in an increase of plasma density. This

magneto-electrostatic plasma containment was investigated with this test source operated with the magnetic filter for a discharge power of 80 V and 3 A. Figure 2 shows the source assembly with the strip-electrodes. The H^- yield (measured from the spectrometer signal) as a function of the plasma electrode bias voltage for three different strip-electrode potentials are shown in Fig. (4). When the strips are biased at +10 V relative to the anode (curve (a)), the optimum H^- yield is about 53% higher than the case when they are biased at the anode potential (curve (c)) for the same discharge current of 3 A. From the Langmuir probe traces obtained in the source chamber, we found that the source plasma density also increases by approximately the same amount. The increase in the extracted H^- ion current in this arrangement is therefore due mainly to the overall improved plasma confinement.

(c) Optimization of source pressure

The dependence of H^- ion yield on gas pressure has been studied and the results are presented in Fig. 5. With the source operating without a filter, and at a discharge power of 80 V and 3 A, the H^- ions extracted increases and then decreases as the pressure inside the source is increased above 1×10^{-3} Torr. Langmuir probe traces taken at the source center and near the extractor indicate that local plasma densities increase continuously with pressure (Fig. 6). Thus, the drop in extracted H^- current at pressures higher than 1×10^{-3} Torr must be related to the relative production and destruction rates of the H^- ions.

When a magnetic filter is installed and operated with the same discharge power, the H^- yield again increases with source pressure (Fig. 5), reaches a maximum at 5×10^{-4} Torr, and then decreases rapidly as pressure is further

increased. Figure 6 shows that the plasma density in the extraction chamber varies with source pressure in exactly the same manner as the extracted H^- ions. However, the plasma density in the source chamber shows no reduction even when the source pressure is higher than 5×10^{-4} Torr. Thus, the presence of the filter enables the source to operate at an optimum pressure that is approximately one half the non-filter case. For the same discharge power, the best H^- yield with the filter is about three times greater than that without the filter. As a result, one can achieve a higher gas efficiency when the multicusp source is operated with a filter. Further improvement in the source gas efficiency will be discussed in the last section.

(d) Optimizing the filter position

In this test source, the mid-plane of the filter was located about 8 cm from the plasma electrode of the extractor. This position had been chosen when this source was originally designed to produce high atomic ion positive hydrogen ion beams.[9] Thus, the extractor electrode would be located outside the magnetic field of the filter in order to eliminate magnetic field effects on the plasma density profile. However, we recognized that this filter position may not be optimized for H^- ion production.

In order to study the dependence of H^- yield on the position of the filter, a moveable water-cooled samarium-cobalt magnet filter unit was installed from the end flange of the source. The position of this filter could be adjusted even while the source was operating.

Figure 7 shows the extracted H^- and electron current for a current discharge power of 80 V and 3 A. As the filter is moved towards the plasma electrode, the extracted H^- current increases steadily but the extracted

electron current drops. A rapid increase in H^- current occurs when the filter is approximately 4 cm from the extraction plane. It is at this position that the extractor enters the filter's magnetic field. The electron current increases again but then falls steeply as the filter approaches the extractor. The reduction in the extracted electron current may arise from the E x B drift extraction geometry. It is also possible that a substantial number of trapped electrons may be swept away by the plasma electrode as it intercepts the magnetic field lines. Nevertheless, the data demonstrates that the H^- current can be increased by almost threefold while the electron current is reduced by a factor of about three as the filter is moved from 12 cm to 26 cm away from the rear end flange. In turn, the ratio of H^- to electron current is also improved by nearly an order of magnitude.

(e) Optimizing the extraction chamber length

The data presented in Sec. (d) show that the extractable H^- current increases as the extraction chamber length is reduced. This seems to indicate that a sizable portion of the extracted H^- ions are formed in the filter region. However, when one moves the filter, the volumes of both the extraction and the source chamber will be changed. This will, in turn, result in a change in plasma densities, electron temperature, axial plasma potential profile and ion species distribution. Any real change in the H^- yield is therefore difficult to interpret. In order to overcome this difficulty, a moveable two-electrode extraction and spectrometer system (shown in Fig. 8) was fabricated. This system allows the source chamber volume to remain constant as the position of extraction relative to the filter is changed (Fig. 1). The plasma electrode of this extractor is water-cooled and the area

of the extraction slot is 0.1 x 1.0 cm^2. Since the separation between the extractor and the mass spectrometer is always maintained at ~7 cm, the operation of the spectrometer will not be affected by the magnetic field of the filter magnets.

Figure 9 summarizes the data that was obtained as the extractor was moved from the edge of the extraction chamber (d=0) towards the plane of the filter (d = 6 cm). At each extractor position d, it was found that a small positive bias potential relative to the anode would enhance the H^- yield accompanied by a reduction in electron current. The optimum bias voltage normally occurs at approximately +4 V. The same observation was reported in a previous experiment (Ref. 3), and it is believed that the elimination of a retarding potential gradient between the plasma electrode and the source plasma plays an important role in this improvement.

The data in Fig. 9(a) shows that a substantial increase in H^- yield (about a factor of <u>six</u>) occurs when the extractor is moved from the edge of the source to a position near the filter. This result is consistent with that obtained with the moveable filter system when the expected change in plasma density is taken into account. The largest part of the extractor power supply drain I^- is composed of electrons. Figure 9(b) and (c) illustrate that this drain current I^- and the extracted positive ion current I^+ behave similarly when d < 3 cm. When d > 3 cm, I^- decreases but the positive ion current drain does not, indicating that the electrons are drifted away by the E x B motion in the acceleration gap, or more readilty collected on the biased plasma electrode.

The total extracted H^- and electron current through the exit aperture has been determined by an electron separator operated with a Faraday cup. With the extractor located at d = 0, the extractable H^- current density for

1 A of discharge current in this test source geometry is 0.12 mA/cm^2 and the ratio of I_e/I_{H-} is 200. But the extractor is moved very close to the filter (d = 6 cm), the H^- current density for the same discharge current increases to 0.7 mA/cm^2 and the ratio of I_e/I_{H-} is less than 2. This large increase in H^- current density will be further studied with much higher discharge current. H^- ion density profile, beam optics, and the exact process of generating the H^- ions will also be investigated.

(f) Optimizing the source chamber length

The results in the previous section suggest that most of the extracted H^- ions are produced within the filter region. However, the interaction particles (electrons, H_2, H_2^+, H_3^+) for forming the negative ions all come from the source chamber. It has been shown that the H^- ion current depends almost linearly with the discharge power in the source chamber.[2] Normally, the shorter the source chamber length, the higher is the source efficiency for a multicusp source operated without a filter. In order to determine the dependence of H^- yield on the length of the source chamber when a filter is present, a moveable water-cooled end flange with four rows of samarium-cobalt magnets attached to it was fabricated. The pair of filament holders was also moveable, so that the distance of the filaments from the end flange could be maintained constant. Figure 10 shows a photograph of the arrangement.

The H^- yield as a function of source pressure at a contant discharge power of 80 V and 3 A for three different end flange positions is presented in Fig. 11. When the end flange was located ~20 cm from the filter (curve a), the maximum H^- yield occurred at a source pressure of 1×10^{-3} Torr. No

significant change in the H^- output was observed as the flange was moved 4 cm closer to the filter, except that a higher optimum gas pressure was required (curve b). As soon as the filament entered into the magnetic field of the filter, the H^- yield started to drop (curve c), and the optimum pressure required was even higher. Thus the variation of the source chamber length has a larger effect on gas efficiency rather than on the arc efficiency for H^- production.

For an H^- source, a low operating pressure is desirable as it results in less stripping in the accelerator gap. The cross-section for this stripping process ($H^- + H_2 \longrightarrow H + H_2 + e$) is very high ($\sim 10^{-15}$ cm^2), and therefore a high concentration of electrons can be extracted with the H^- ions. For this reason, one should extend the source chamber length to obtain the lowest practical operating pressure.

The results of the optimization processes indicate that one can further increase the H^- yield of a filtered-multicusp source. Additional work will be required to determine if the optimized geometry is useful for large area sources needed for neutral beam systems.

Acknowledgments

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Figure Caption

Fig. 1 Schematic diagram of the multicusp ion source equipped with a magnetic filter and a moveable extraction-spectrometer system.

Fig. 2 A plot of the spectrometer signal for the H^- ion and the extracted positive ion current density as a function of the discharge voltage. The discharge current is maintained at 5 A.

Fig. 3 The ion source chamber with the filter and the strip-electrodes installed.

Fig. 4 A plot of the spectrometer signal for the H^- ion as a function of the plasma electrode biasing voltage for three different strip-electrode potentials.

Fig. 5 The spectrometer signal for the H^- ion as a function of the source pressure when the source is operated with and without a filter.

Fig. 6 Plasma densities measured at the center of the discharge chamber and near the extractor when the source is operated with and without a filter.

Fig. 7 A plot of the spectrometer signal for the H^- ion and the power supply drain current as a function of the filter position x. The surface of the end flange is located at x = 0.

Fig. 8 A moveable two-electrode extraction and spectrometer system.

Fig. 9 (a) The spectrometer signal for the H^- ion, (b) the power supply drain current, and (c) the extracted positive ion current as a function of the extractor position.

Fig. 10 A moveable filament together with a moveable water-cooled end flange with permanent magnets attached to it.

Fig. 11 A plot of the spectrometer signal for the H^- ion as a function of the source pressure for three different end flange positions.

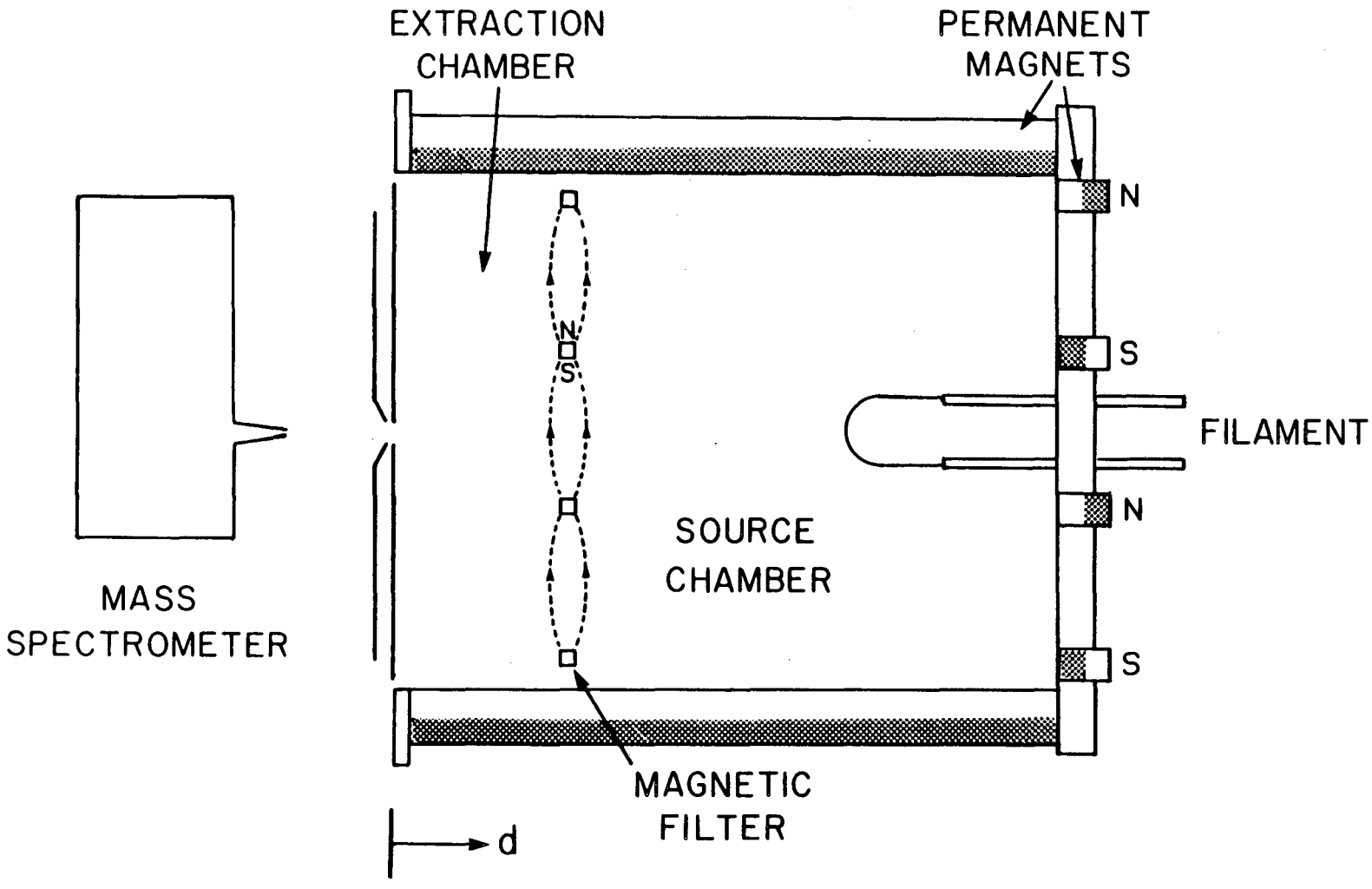

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Fig. 1

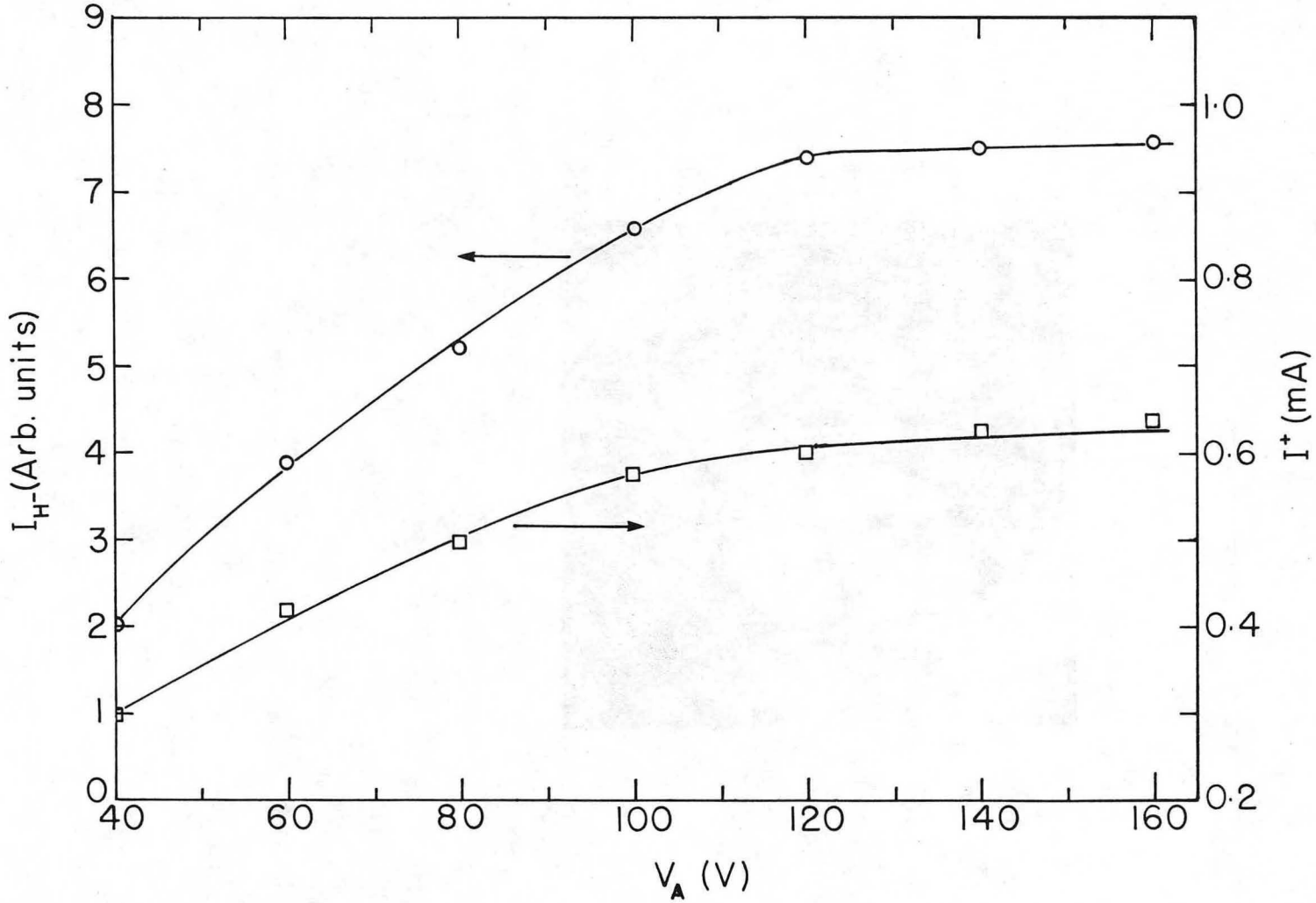

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Fig. 2

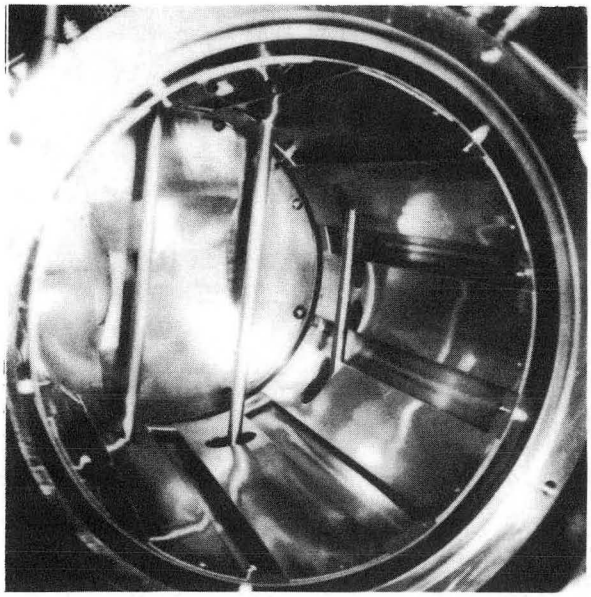

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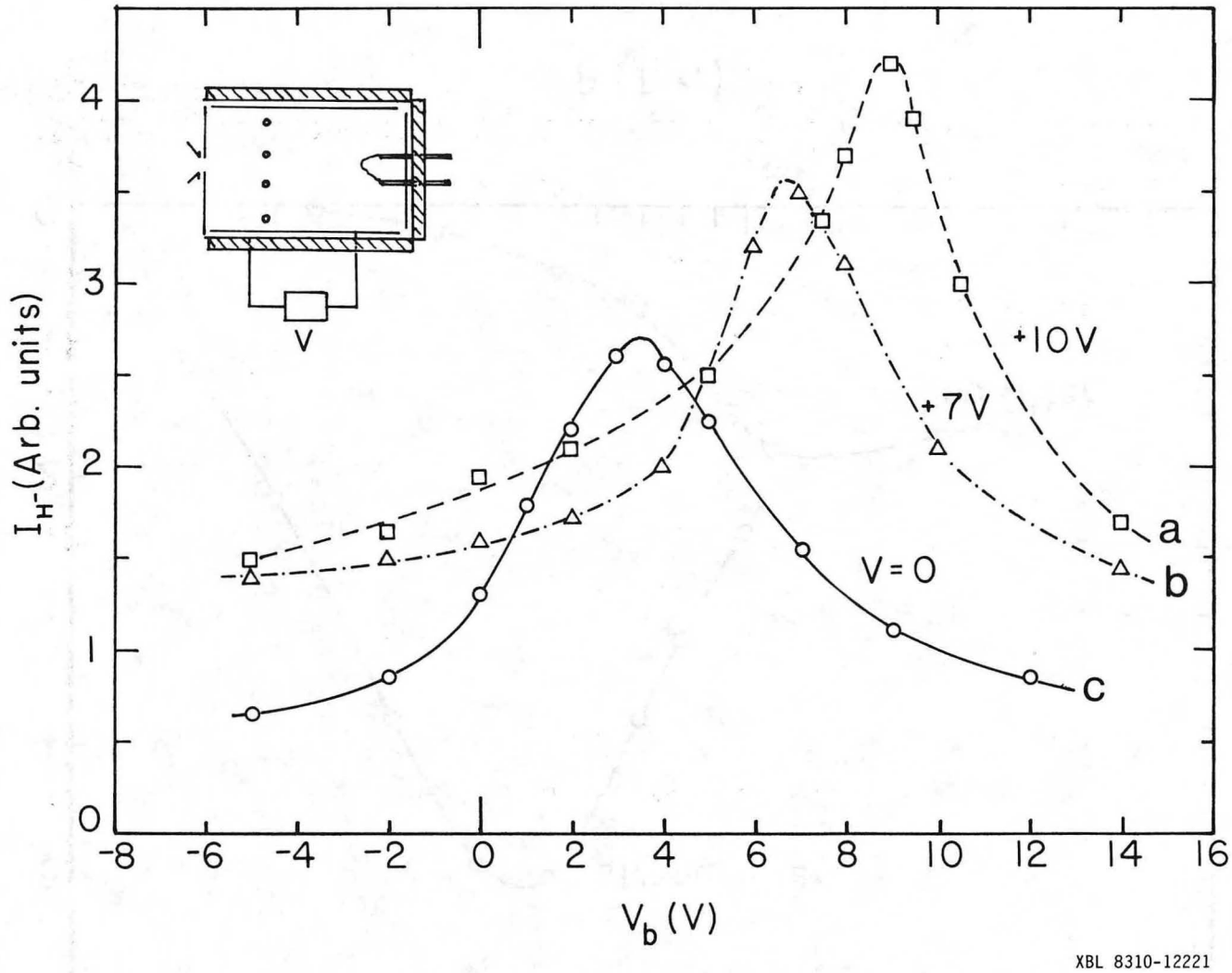
Fig. 3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+7V
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a
b
c
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V_b (V)
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2
3
4
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Fig. 4

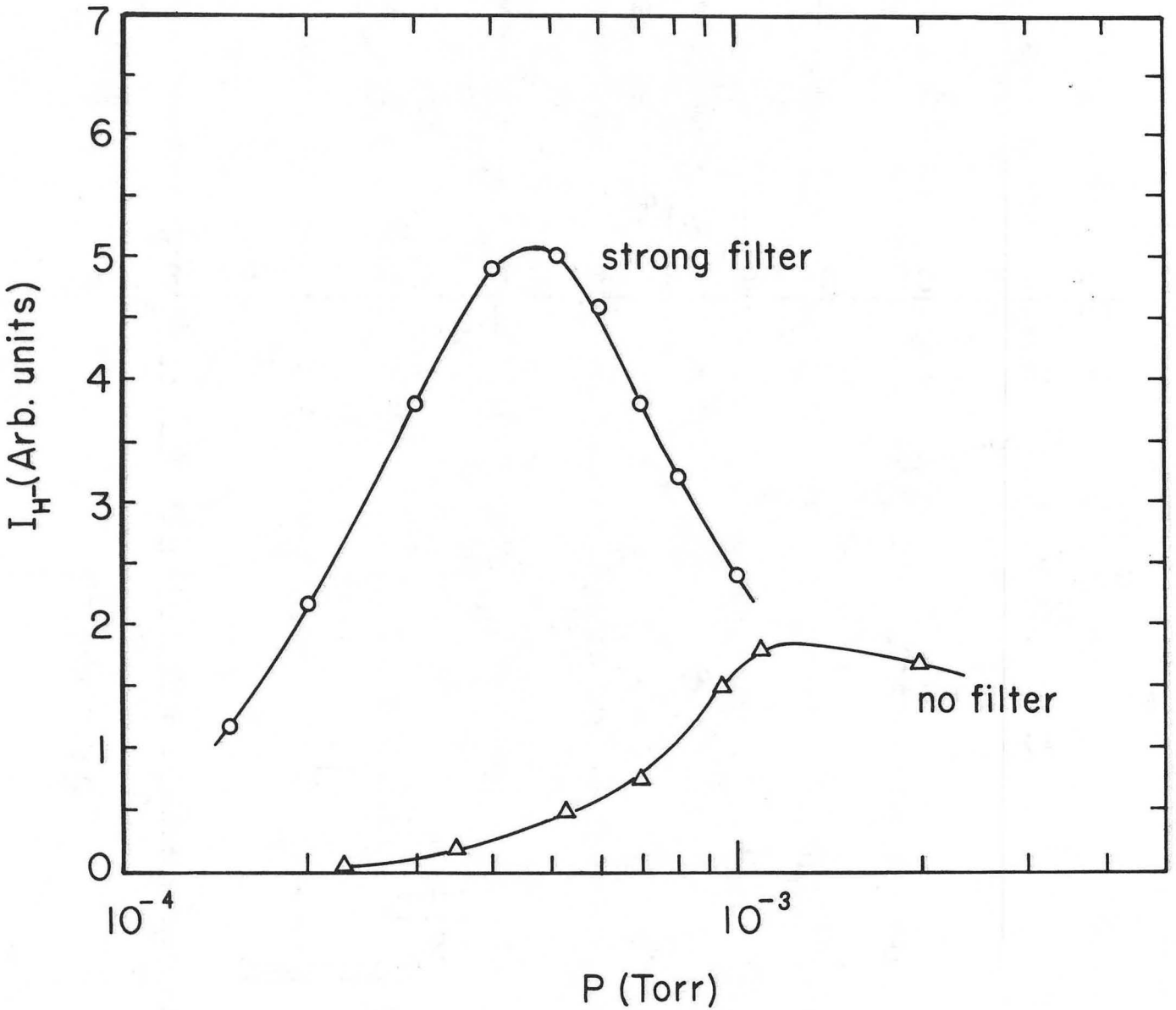

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Fig. 5

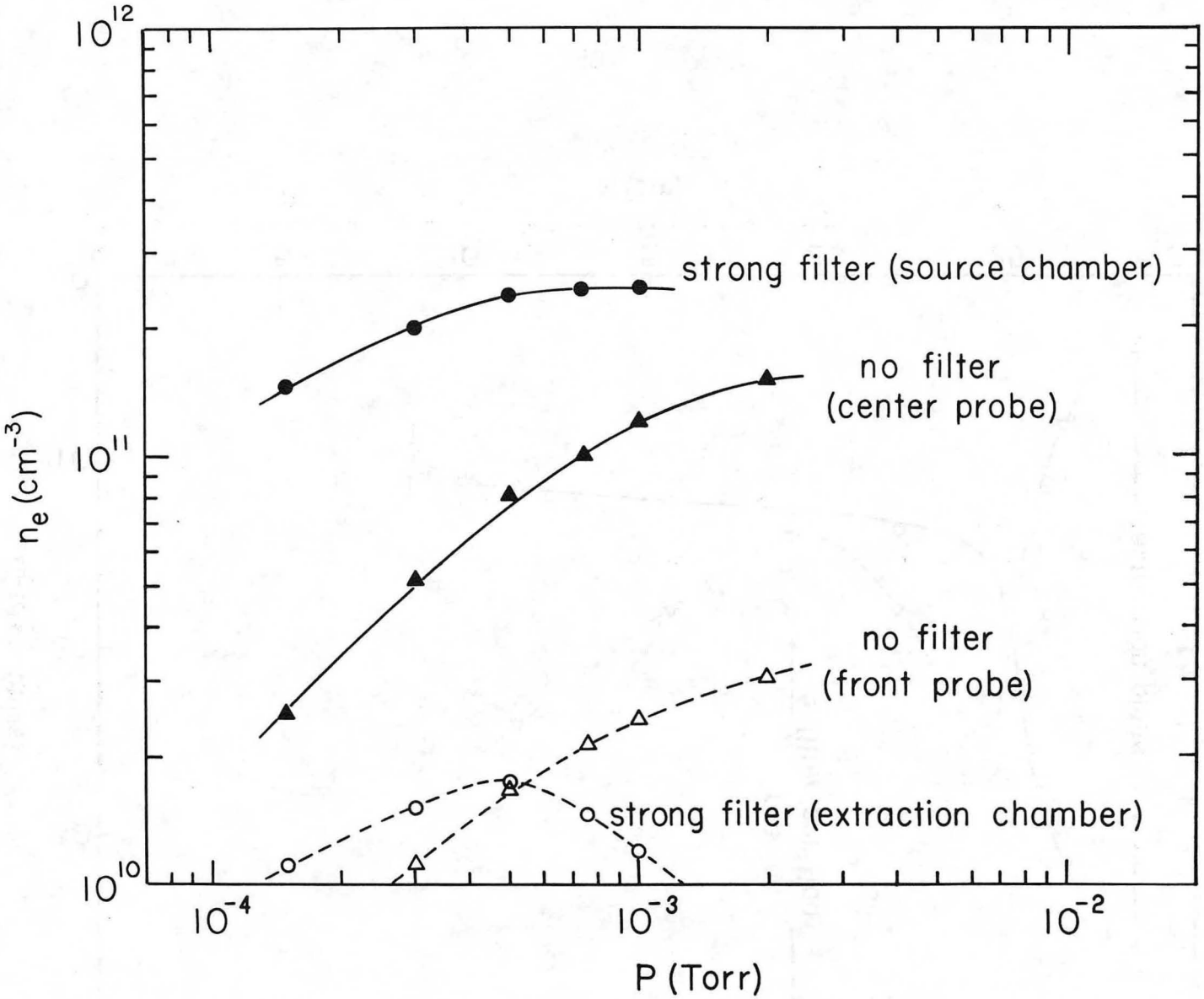

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Fig. 6

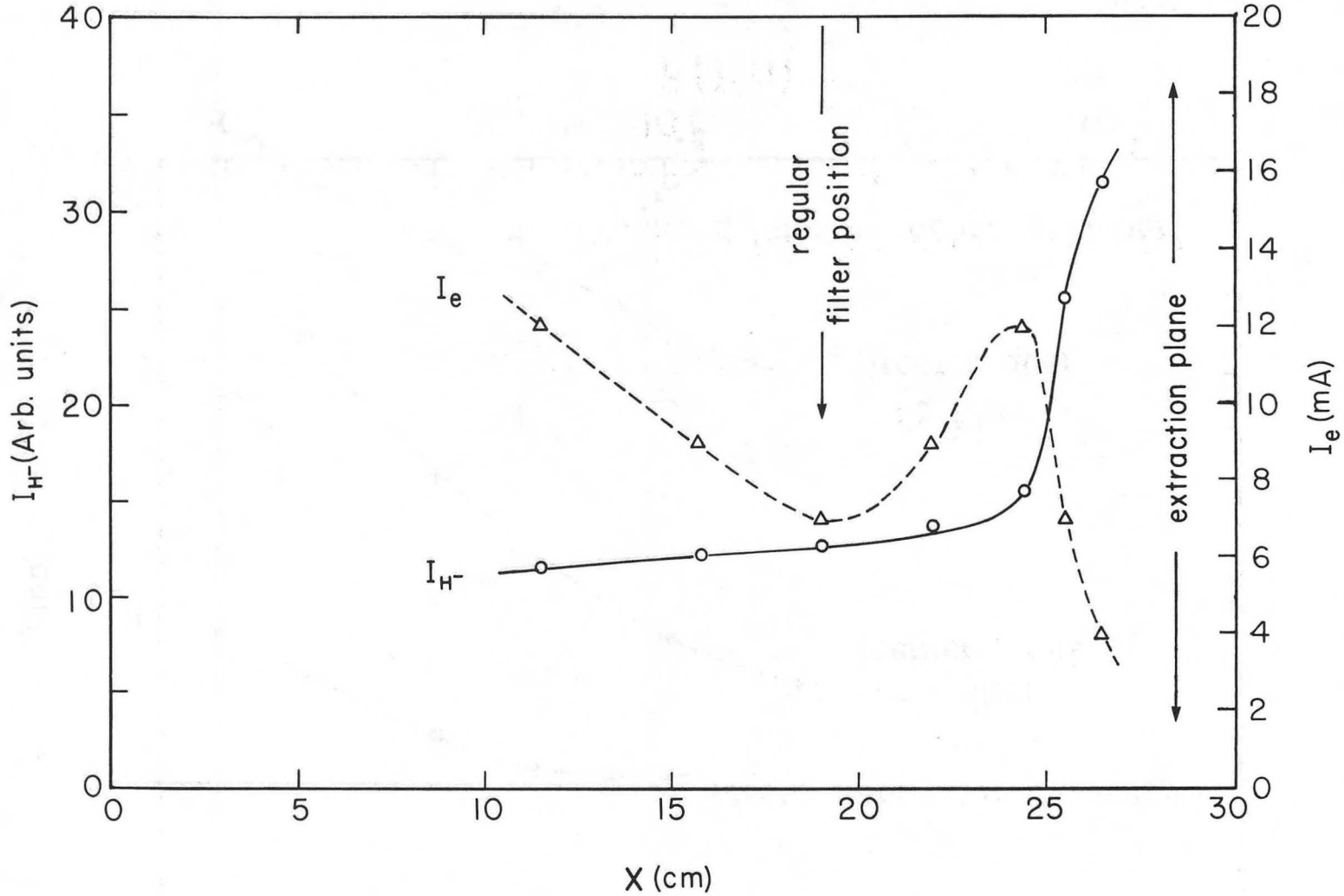

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Fig. 7

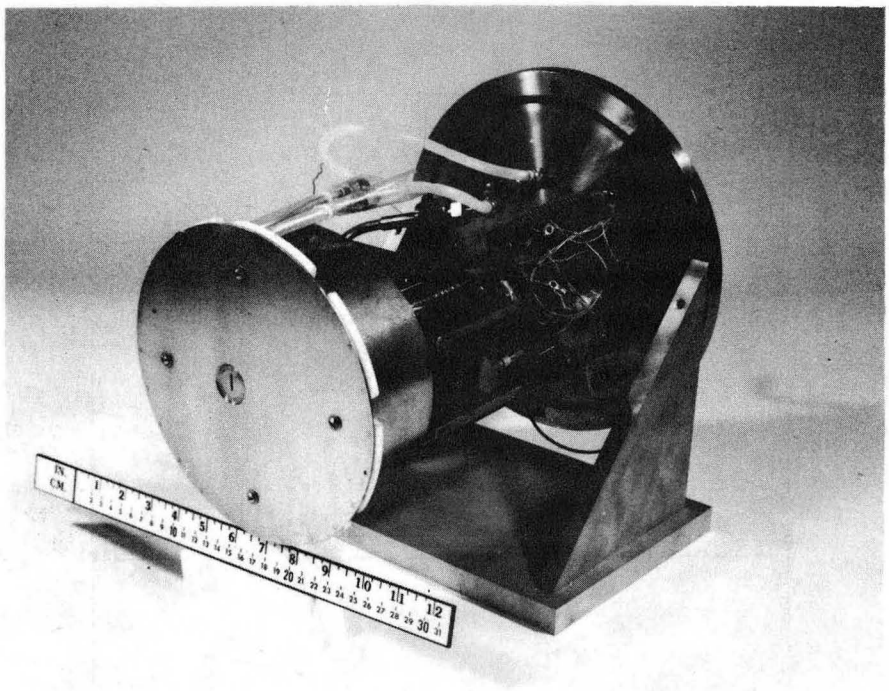

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Fig. 8

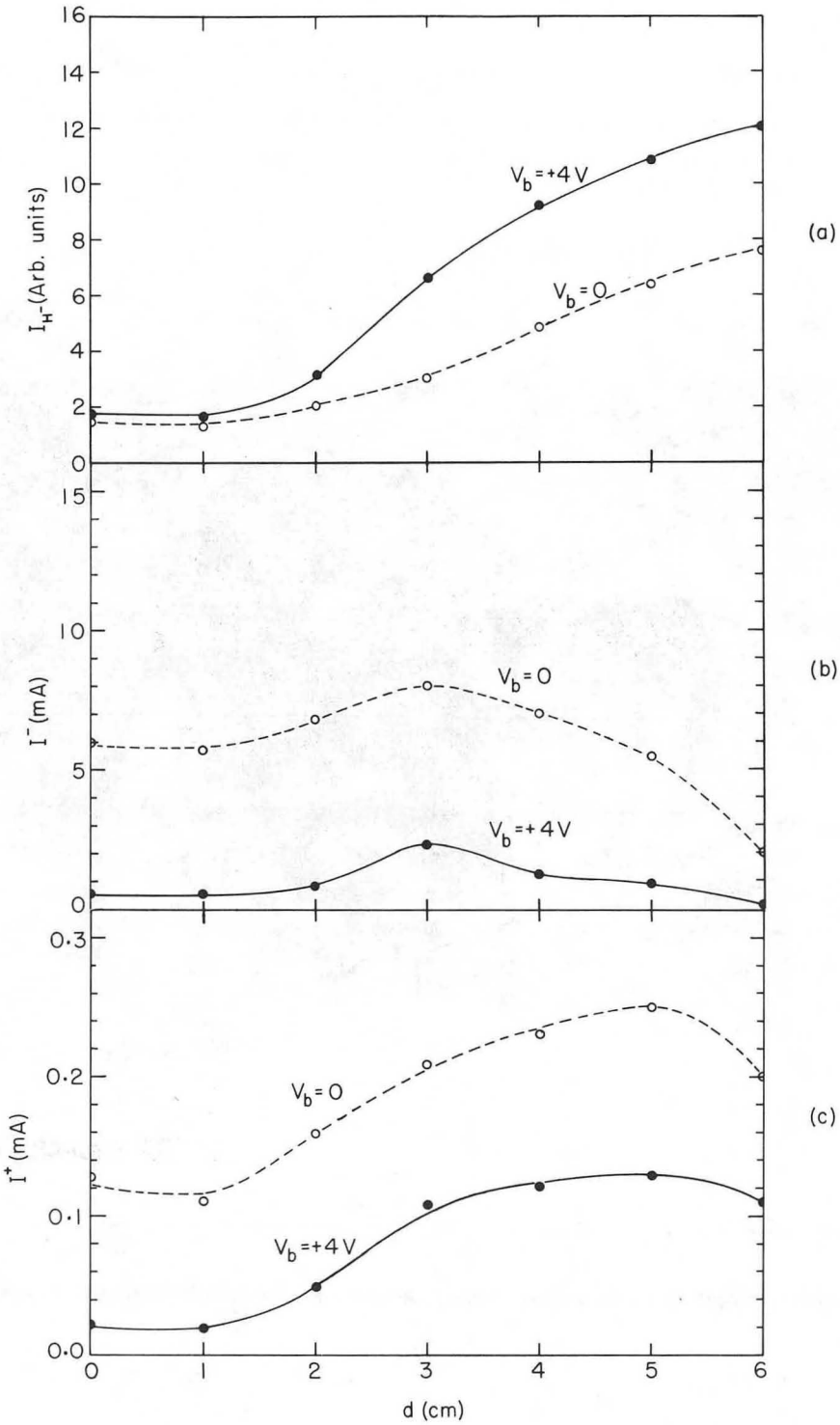

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Fig. 9

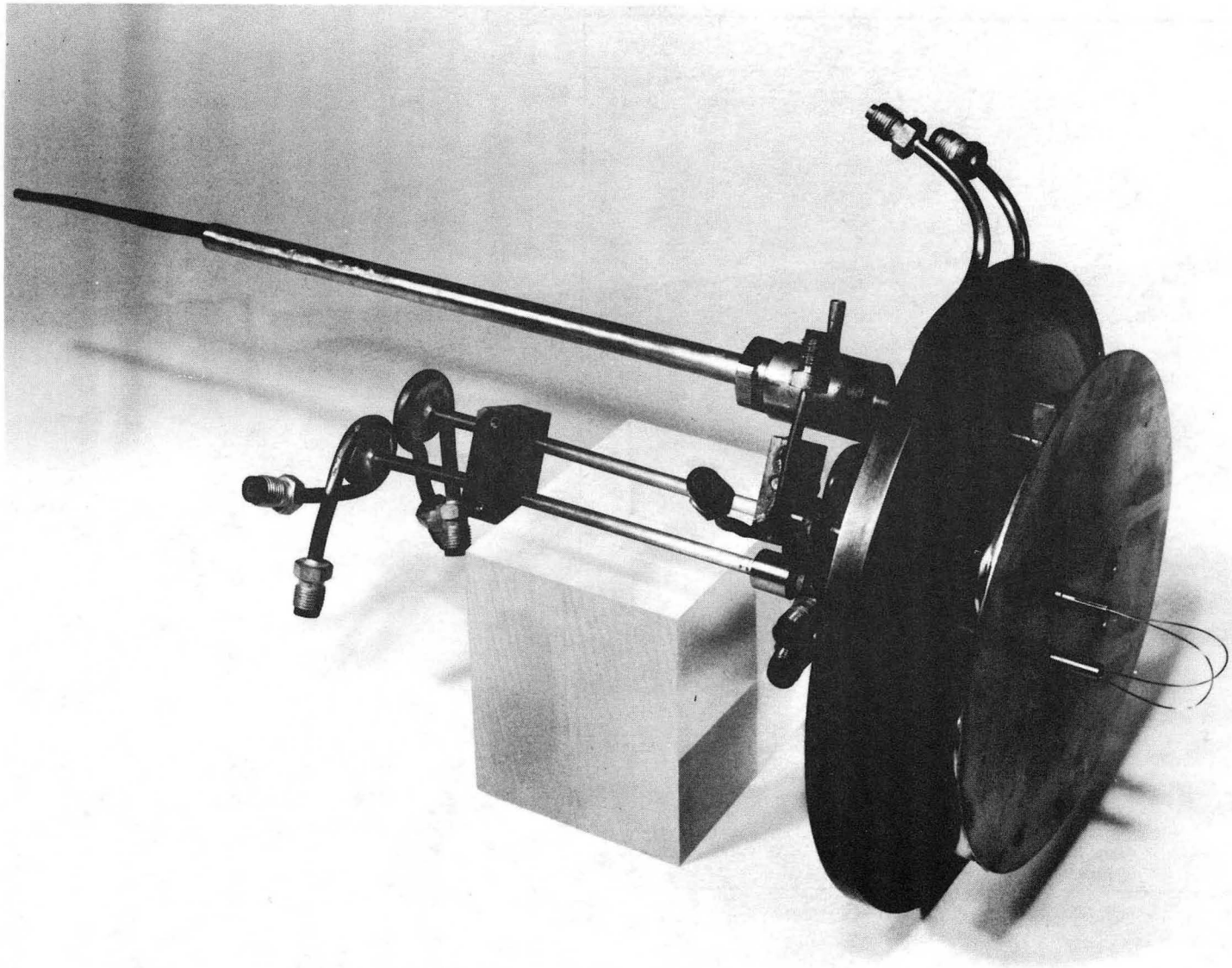

Fig. 10

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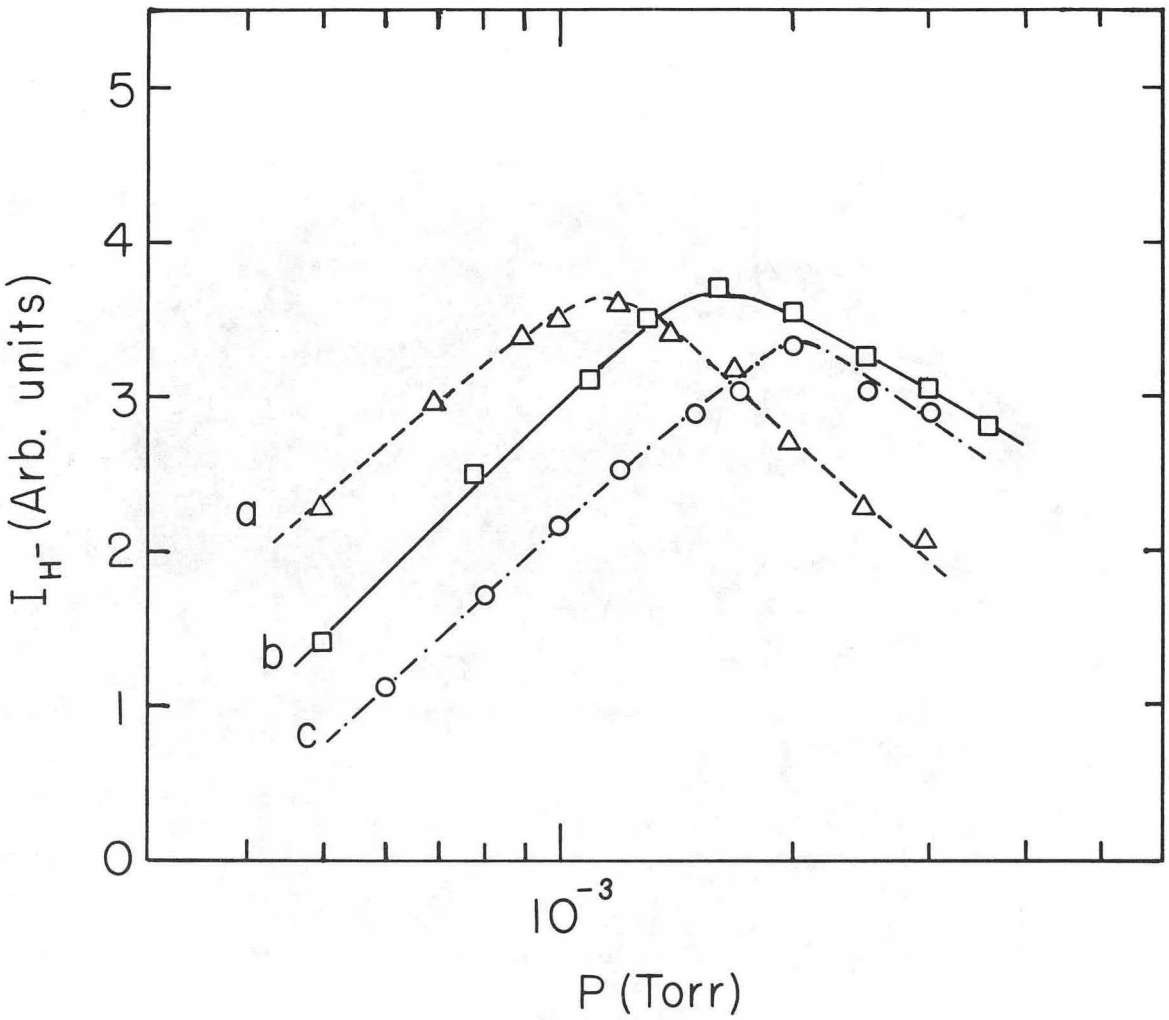

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Fig. 11

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