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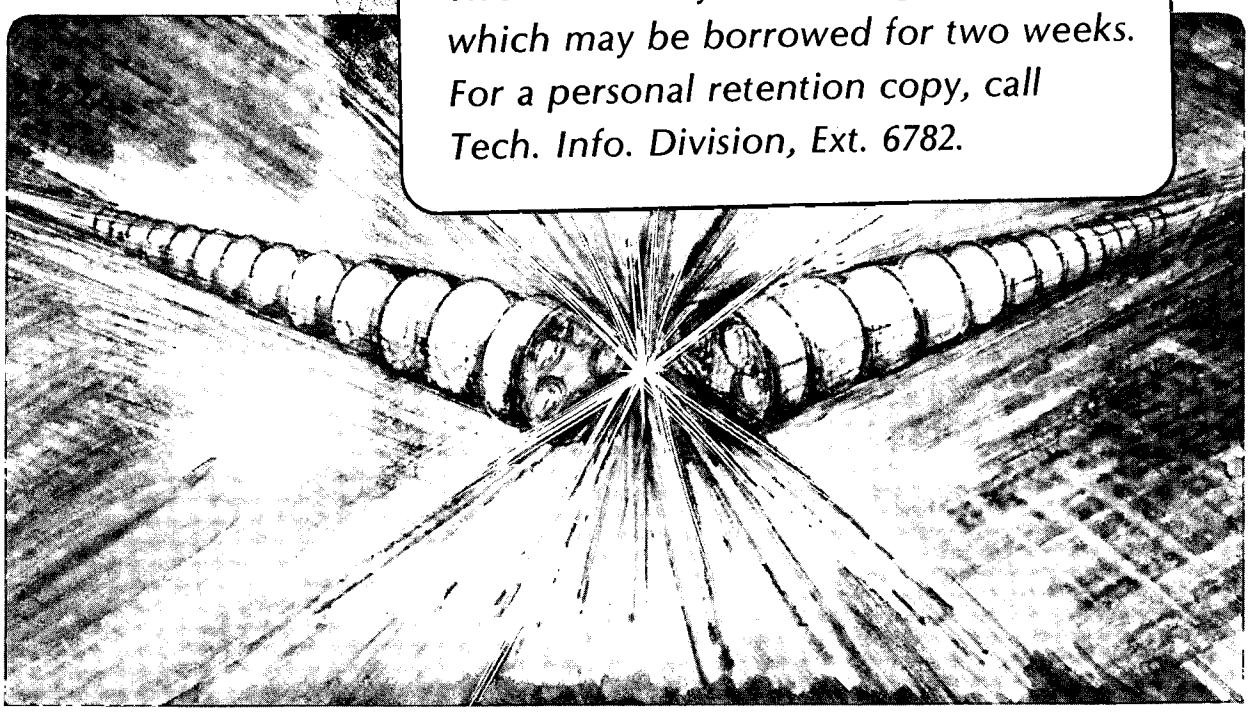

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A Technique to Increase the H^+ Ion Fraction in a Multicusp Source*

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Abstract

It is possible to filter out the primary ionizing electrons from the ion extraction region of a multicusp source by installing the filament inside the dipole fields of the permanent magnets and thereby enhance the H^+ ion species in the extracted beam. An optimum position of the filament has been determined such that a quiescent plasma together with a uniform plasma density profile across the extraction plane can be obtained.

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Introduction

Multicusp plasma generators are capable of producing large volumes of uniform and quiescent plasma with densities exceeding 10^{12} ions/c.c.[1,2] For this reason, there has been a growing interest in applying such devices as ion sources for neutral beam injection systems[3-6] and for particle accelerators.[7,8]

To increase plasma penetration by a neutral beam, a high percentage of H^+ or D^+ ion is desired. It has been found that the presence of primary ionizing electrons in the vicinity of the ion extraction grid increases the percentage of H_2^+ or D_2^+ ions in the extracted beam.[9] The addition of a permanent magnet filter [9,10] to a multicusp ion source can eliminate the presence of the ionizing electrons in the front region of the source. The use of this filter arrangement with the longitudinal cusp geometry greatly improves the atomic species as well as the source operability and the plasma density profile.[9-11]

In this paper, a new scheme is presented which can provide the same effect as a permanent magnet filter. It is shown that if the filament cathodes are properly placed inside the dipole fields generated by the permanent magnet rows on the end flange of a multicusp source, the H^+ ion fraction in the extracted beam can be enhanced. This "rodless" filter arrangement produces a uniform plasma density profile at the extraction plane and maintains the quiescence of the source plasma. It is also found that the 30% drop in the extractable ion current density can be partially recovered by installing negatively biased electrodes on some of the line-cusps.

Experimental Setup

Figure 1 shows a schematic diagram of the experimental setup. The ion source is a cylindrical stainless steel chamber (20 cm diam by 24 cm long) with the open end enclosed by a three grid ion extraction system. The first or plasma grid was masked down to a small (0.15 x 1.5 cm^2) extraction slot in order to reduce the gas flow and the current drawn by the high voltage accel power supply. The external surface of the source chamber is surrounded by ten columns of samarium-cobalt magnets ($B_{max} \approx 3.6$ kG), forming line-cusps parallel to the source axis with the north and south poles alternately facing the plasma. These magnet columns are connected at the end flange by four extra rows of magnets which are spaced 6 cm apart.

Primary electrons are emitted from a 0.05-cm-diam hair-pin tungsten filament which is mounted on a pair of movable copper rods. The plane formed by this filament is parallel to the end flange. With this arrangement, the position of the filament (d) can be varied by moving the rods in or out of the source chamber. The entire chamber together with the end flange form the anode for the discharge.

Two stainless steel electrodes (1 cm wide by 10 cm long) are installed just above the surface of the two center magnet rows as shown in Fig. 1. By applying a negative bias potential equal to or greater than the discharge voltage, the primary electrons will be reflected electrostatically at these two line-cusps.

During normal operation the hydrogen pressure outside the source was maintained at 1×10^{-4} Torr as measured by an ionization gauge. The actual pressure inside the source was approximately an order of magnitude higher. Plasma parameters and the density profile in front of the plasma grid were

obtained by a movable Langmuir probe.

To extract positive ions, the source chamber was biased at approximately +300 V with respect to ground. The plasma grid was left floating electrically and the second and third grids were connected to ground. A compact magnetic-deflection mass spectrometer[12] located just downstream from the extractor was used to measure the hydrogen ion species distribution of the extracted beam.

Experimental Results

The source was first operated with the hair-pin filament located near the center of the source chamber (d = 11 cm) where the magnetic field generated by the permanent magnets was essentially zero. A hydrogen plasma was produced with a discharge voltage of 80 V and a discharge current of 5 A. The spectrometer output signal in Fig. 2(a) shows that the ion species distribution (H^+ : H_2^+ : H_3^+) in the extracted beam is 17 ; 37 : 46. The low floating potential of the plasma grid ($V_f \approx -40$ V) together with the probe trace of Fig. 3(a) show that there is a substantial number of hot ionizing electrons in the extraction region. As a result, H_2^+ ions are formed near the plasma grid and are extracted from the source to form part of the beam.

When the filament position d is varied from 11 to 6 cm, the data in Fig. 4 shows that there are no significant changes in the ion species distribution, the plasma grid floating potential V_f, and the ion saturation current I_i to the probe. However, a further reduction in the distance d results in a rapid change of the ion species distribution as well as a change in V_f and I_i. According to the plot of the measured B-field versus

the distance d shown in Fig. 5, the filament is now positioned within the dipole field region which has sufficient magnetic flux to confine the primary electrons emitted.

The spectrometer output signal in Fig. 2(b) is obtained with the filament located at d = 4.75 cm. It can be seen that the H_2^+ ion fraction has dropped to 9% while the H^+ and H_3^+ ion concentration has increased to 27 and 64% respectively. In fact, the probe trace of Fig. 3(b) together with the observed high floating potential of the plasma grid ($V_f \approx -10$ V) demonstrate that very few high energy electrons arrive at the extraction region. The primary ionizing electrons emitted from the filament are trapped in the cusp fields and thus they are "filtered" from the front portion of the source. As in the case of the physical permanent magnet filter, only cold electrons with $T_e \approx 2$ eV are found near the extractor.[9] In fact, the integrated magnetic flux from the source center to d = 4.75 cm is about 117 G-cm, which is slightly higher than the value we found for the optimized magnetic filter (for 80 eV electrons).[10]

Figure 4(c) also shows that the extractable ion current density and therefore the efficiency of the source decreases by approximately 30% when the filament position d is moved from 11 to 4.75 cm. However, there is no appreciable change in the plasma density fluctuation level as illustrated by the ac probe signals shown in Figs. 3(a) and (b). A plot of the plasma density profile obtained by scanning the Langmuir probe radially in front of the plasma grid is presented in Fig. 6. The profile is essentially uniform within an extraction region of 7-cm-diam, which is about the same as that obtained when the filament is located at the source center.

As the filament is moved further towards the end flange, there is a slight decrease in the H^+ ion percentage in the extracted beam (Fig. 4(a)). At d = 3.9 cm, the ion current density has decreased by about 40% (Fig. 4 (c)), and the plasma noise level increases. According to Fig. 3, the density fluctuation is nearly four times as large as that with the filament located at the source center. A similar result has also been observed by Hershkowitz et al.[13] All these measurements indicate that d = 4.75 cm is the optimum position of the filament for this geometry if one is seeking a uniform and quiescent plasma together with a higher percentage of atomic hydrogen ions for extraction.

Figure 7 shows the ion species distribution for two different filament positions (d = 11 and 4.75 cm) as a function of the discharge current I_A. It is difficult to obtain more than 7 A of discharge current when the filament is located at the source center. But the same filament can provide 10 A of discharge current if it is placed at d = 4.75 cm. Since the discharge voltage is kept constant, the increased emission may arise from the increased plasma density near the filament region. This in turn will produce a thinner sheath around the filament wire. Consequently, a higher electron current can be extracted from the filament surface according to Child's Law.[14] At this filament position, the H_2^+ ion fraction is about thirty percentage points lower while the H^+ ion concentration is about ten percentage points higher. The extractable ion current density is approximately 10 mA/cm^2 for I_A = 10 A. These results are similar to those obtained with an optimized permanent magnet filter.[10]

An attempt has also been made to increase the source efficiency by installing two strip electrodes just above the surface of the two center magnet rows on the end flange. When the filament is located at d = 4.75 cm, the erosion marks on these electrodes (when operated at the anode potential)

indicate that the primary electrons are lost mainly to these two line-cusps. By biasing these electrodes at a potential equal to or greater than the discharge voltage, the primaries are reflected electrostatically at the two ends of the flux tubes. As a result, they are able to perform more ionization and dissociation processes, in a manner similar to the reflex-arc discharge.

The effect of applying a negative bias potential V_b on these electrodes with respect to the chamber wall can be seen from the probe characteristics shown in Fig. 8. With V_b = -90 V, the plasma density increases by approximately 14% and the density fluctuation level even decreases slightly. The spectrometer output signal in Fig. 2(c) shows that the H^+ ion percentage has increased from 27 to 29%. Thus, this arrangement recovers part of the loss in source efficiency when the filament is moved from 11 to 4.75 cm without generating any additional perturbation to the source plasma.

We have also tested a multiple filament arrangement by installing four shorter hair-pin tungsten filaments in between two rings of magnets on the end flange. A higher discharge current and therefore higher plasma density can thus be obtained. The results are similar to the single filament configuration. At the optimum filament position (with integrated magnetic flux $\approx$ 117 G-cm), the H^+ ion species fraction increases to 43% with I_A = 20 A.

Acknowledgments

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Figure Captions

Fig. 1 Schematic diagram of the multicusp ion source with the movable filament.

Fig. 2 Spectrometer output signal showing the distribution of hydrogen ion species for a discharge voltage of 80 V and a discharge current of 5 A when the filament is located at (a) 11 cm, (b) 4.75 cm, and (c) 4.75 cm from the end flange but with the strip electrodes biased at -90 V.

Fig. 3 Langmuir probe characteristics and plasma density fluctuation levels obtained near the plasma grid when the filament is located at (a) 11 cm, (b) 4.75 cm, and (c) 4 cm from the end flange.

Fig. 4 (a) The hydrogen ion species distribution, (b) the plasma grid floating potential, and (c) the ion saturation current obtained by a Langmuir probe near the extractor as a function of the filament position with a discharge voltage of 80 V and a discharge current of 5 A.

Fig. 5 A plot of the magnetic field component B_θ, measured between two center magnet rows on the end flange, as a function of the axial position.

Fig. 6 A plot of the ion saturation current as a function of the radial position in front of the plasma grid.

Fig. 7 Hydrogen ion species distribution as a function of discharge current with the filament located at 4.75 cm (solid lines) and at 11 cm (dotted lines). Discharge voltage is maintained at 80 V.

Fig. 8 Langmuir probe traces and plasma density fluctuation level obtained with the strip-electrodes biased at (A) anode potential, and (B) -90 V with respect to the anode. The plasma is generated with a discharge

voltage of 80 V and a discharge current of 5 A.

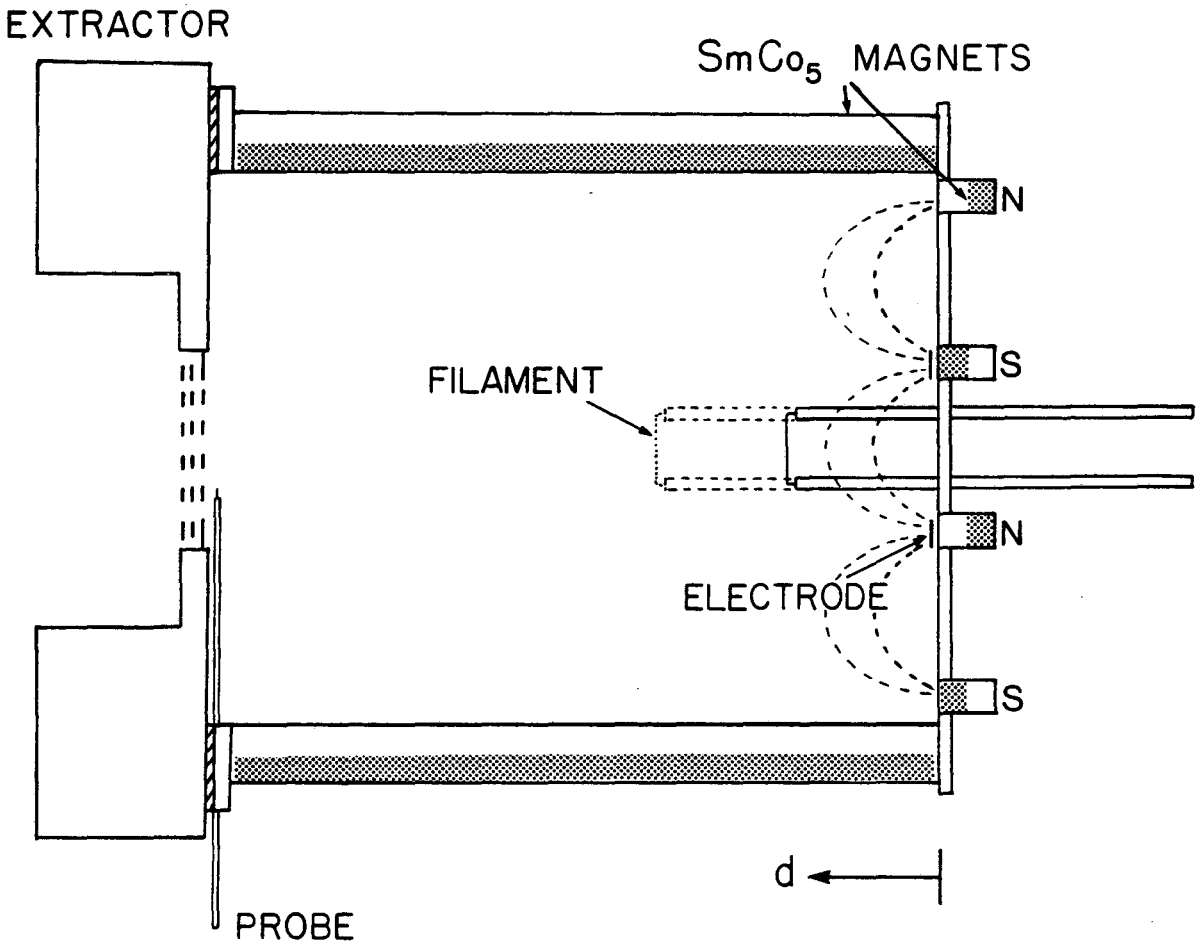

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Fig. 1

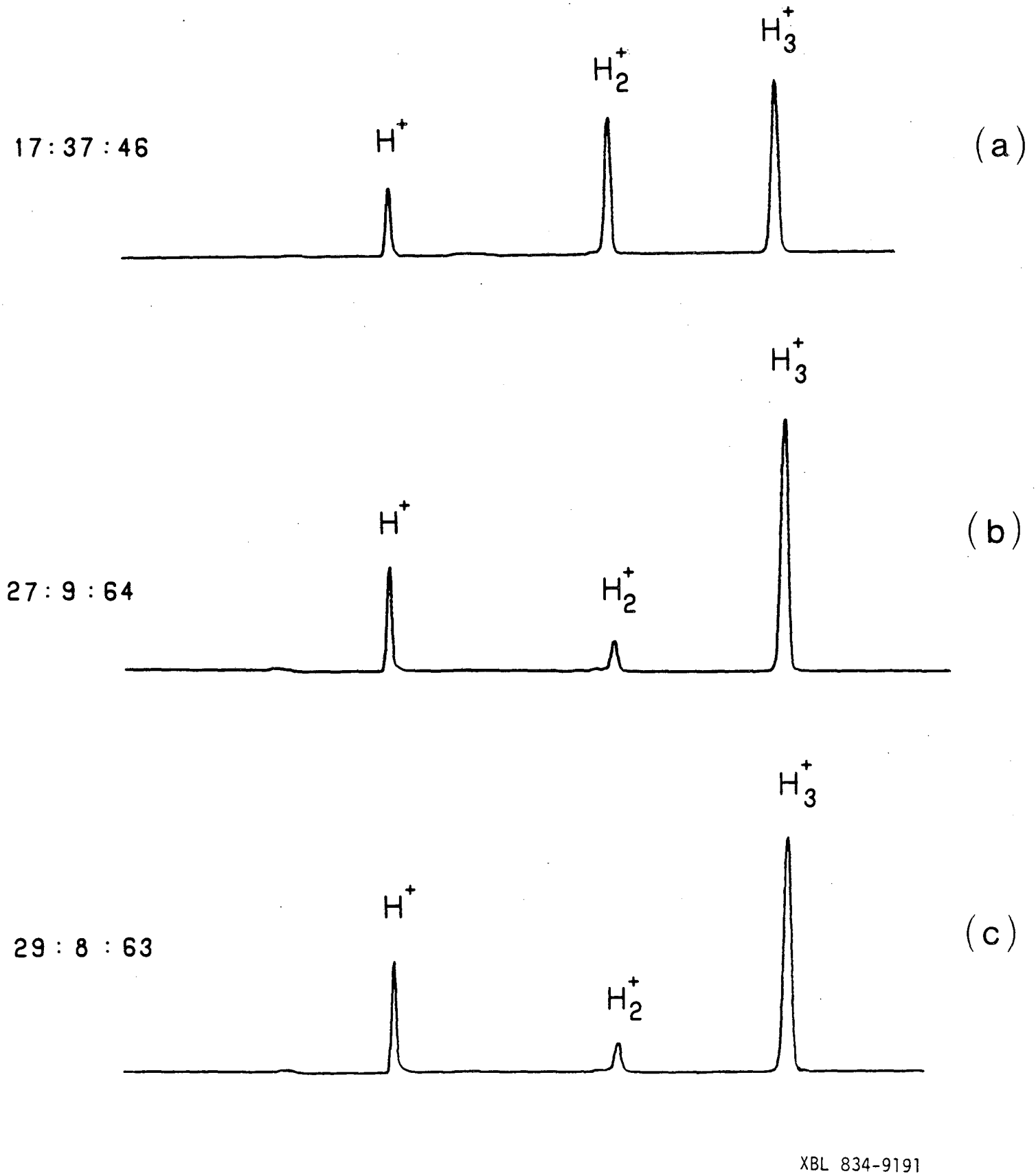

Fig. 2

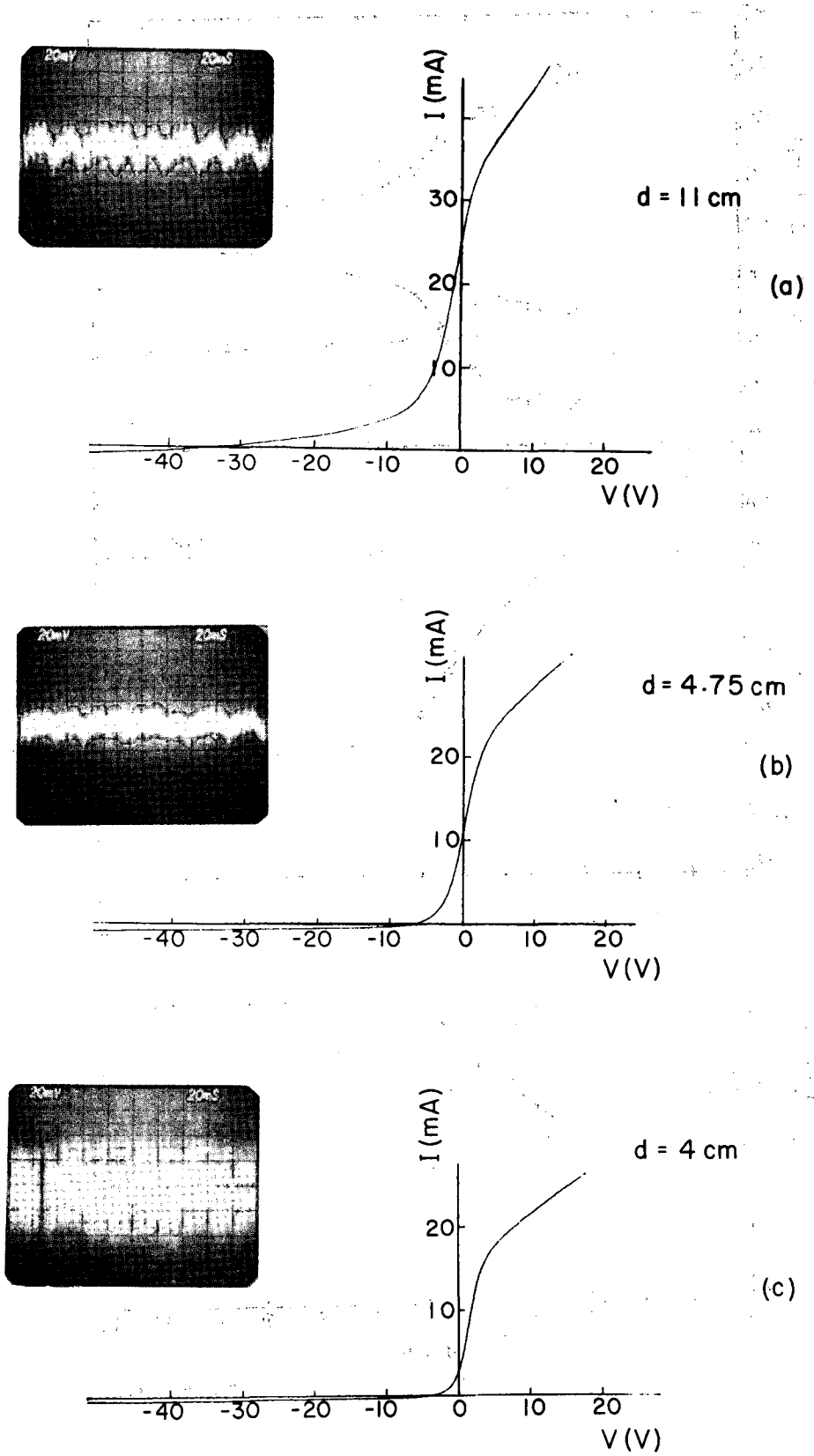

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Fig. 3

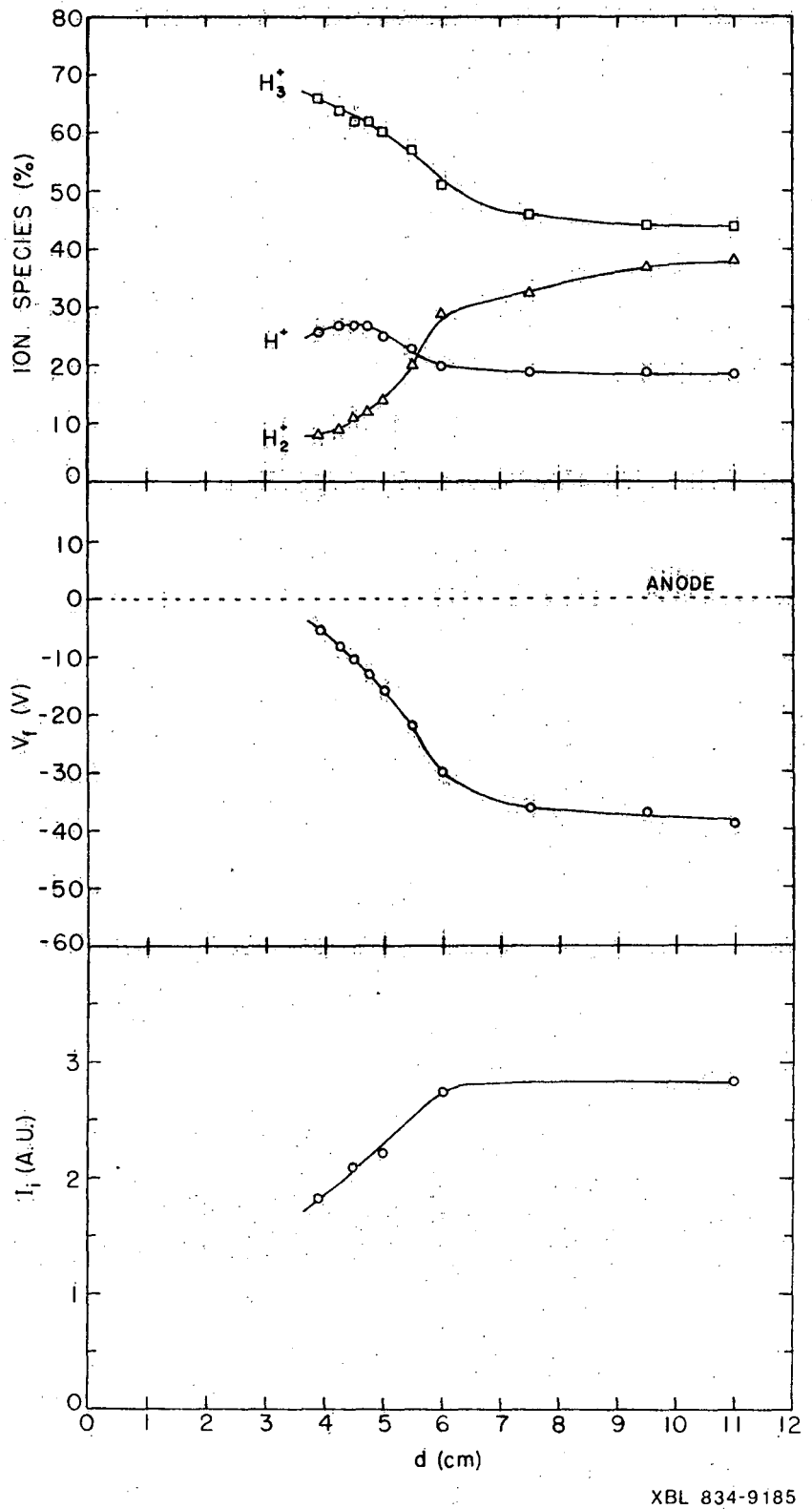

Fig. 4

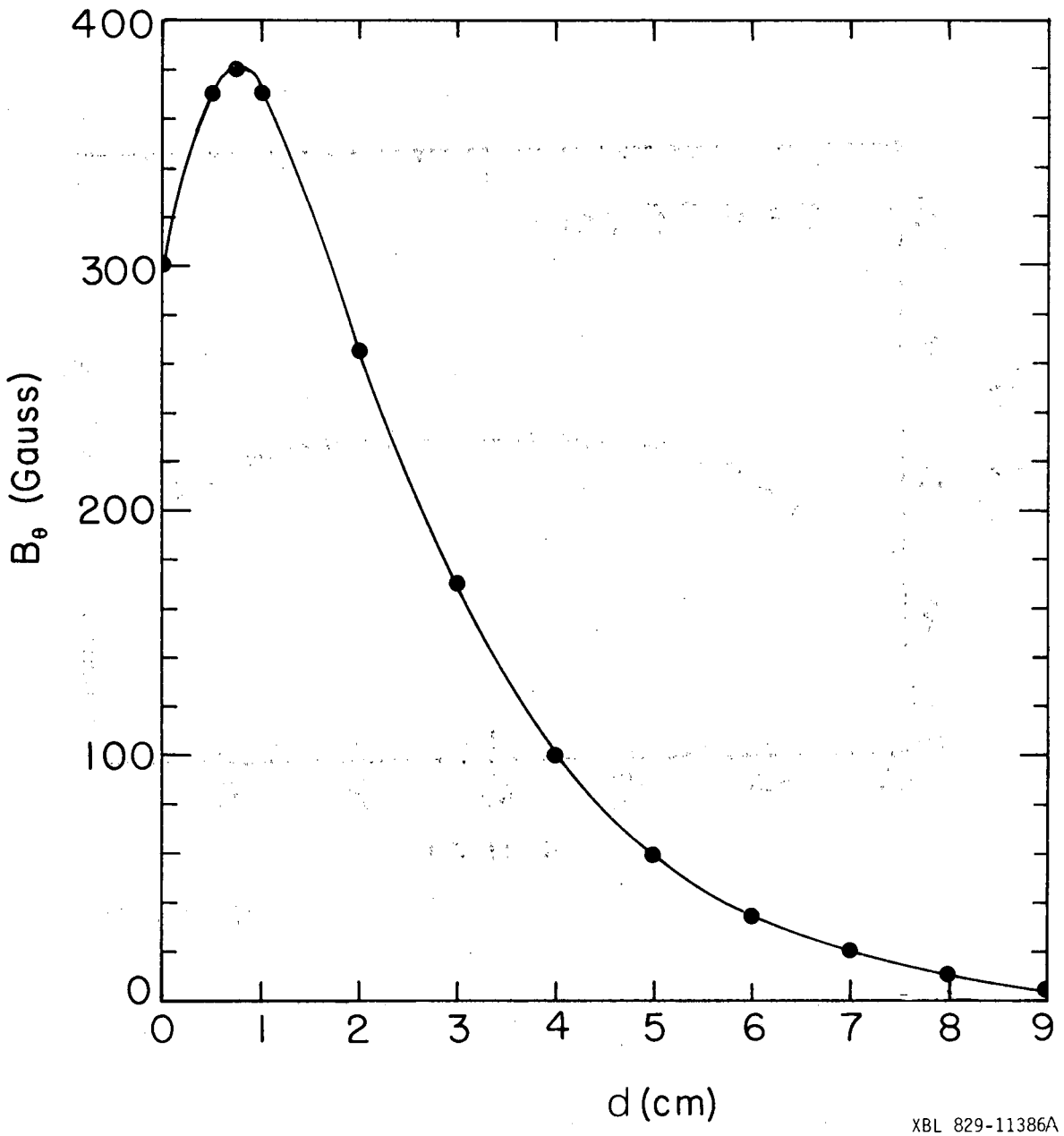

Fig. 5

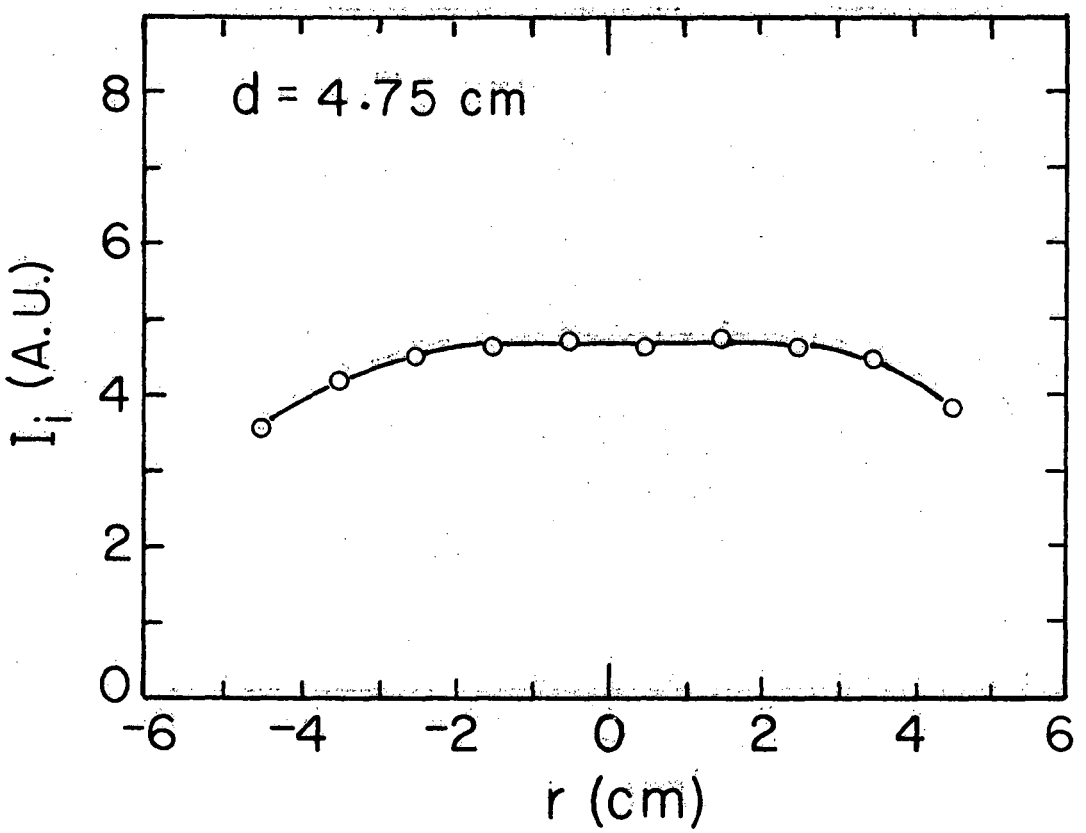

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Fig. 6

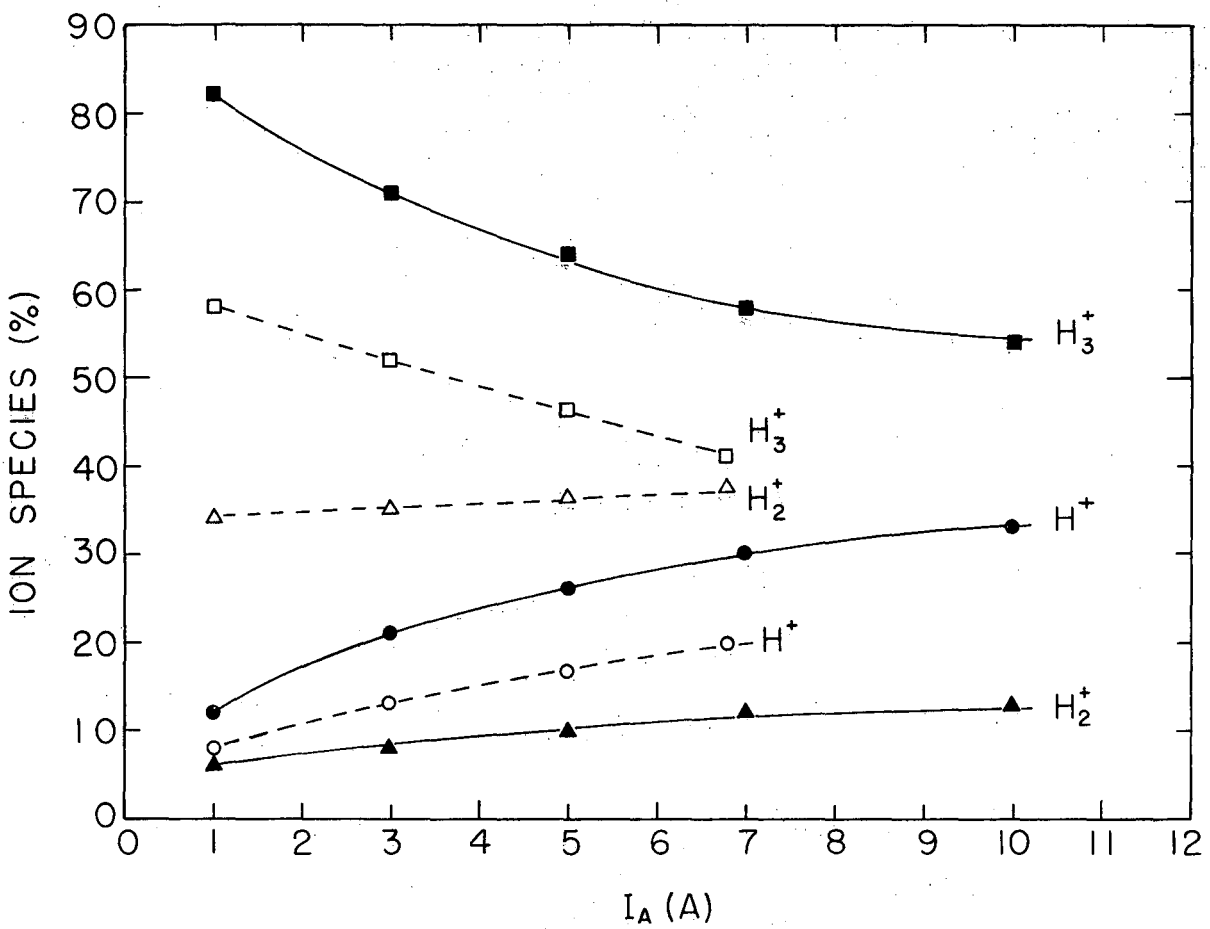

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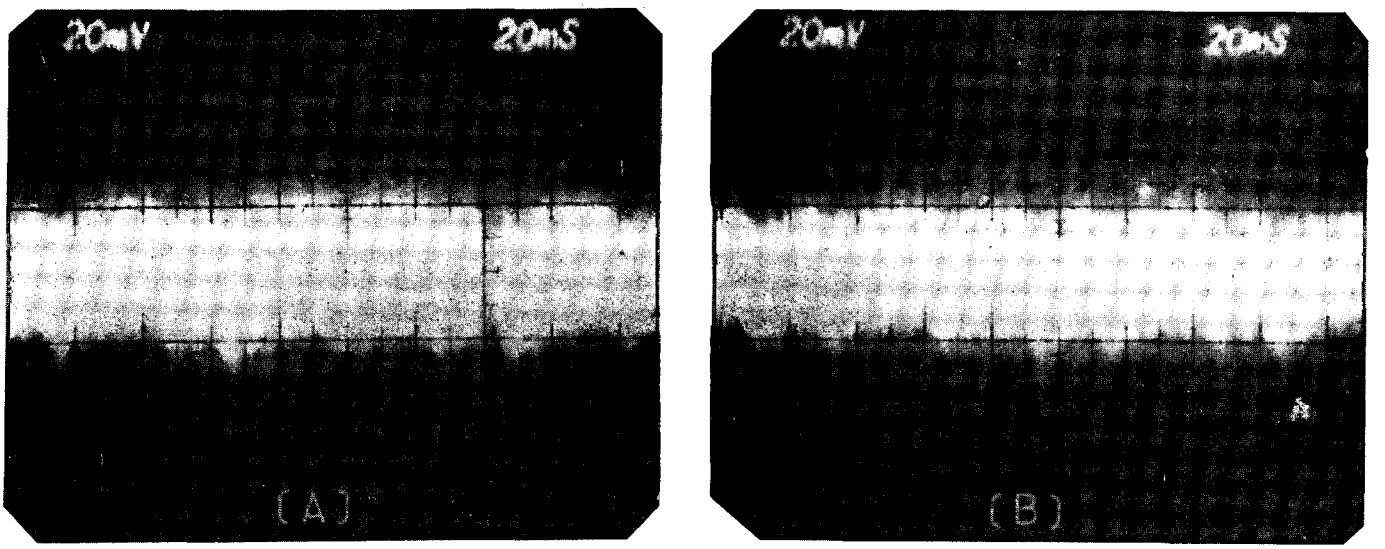
Fig. 7



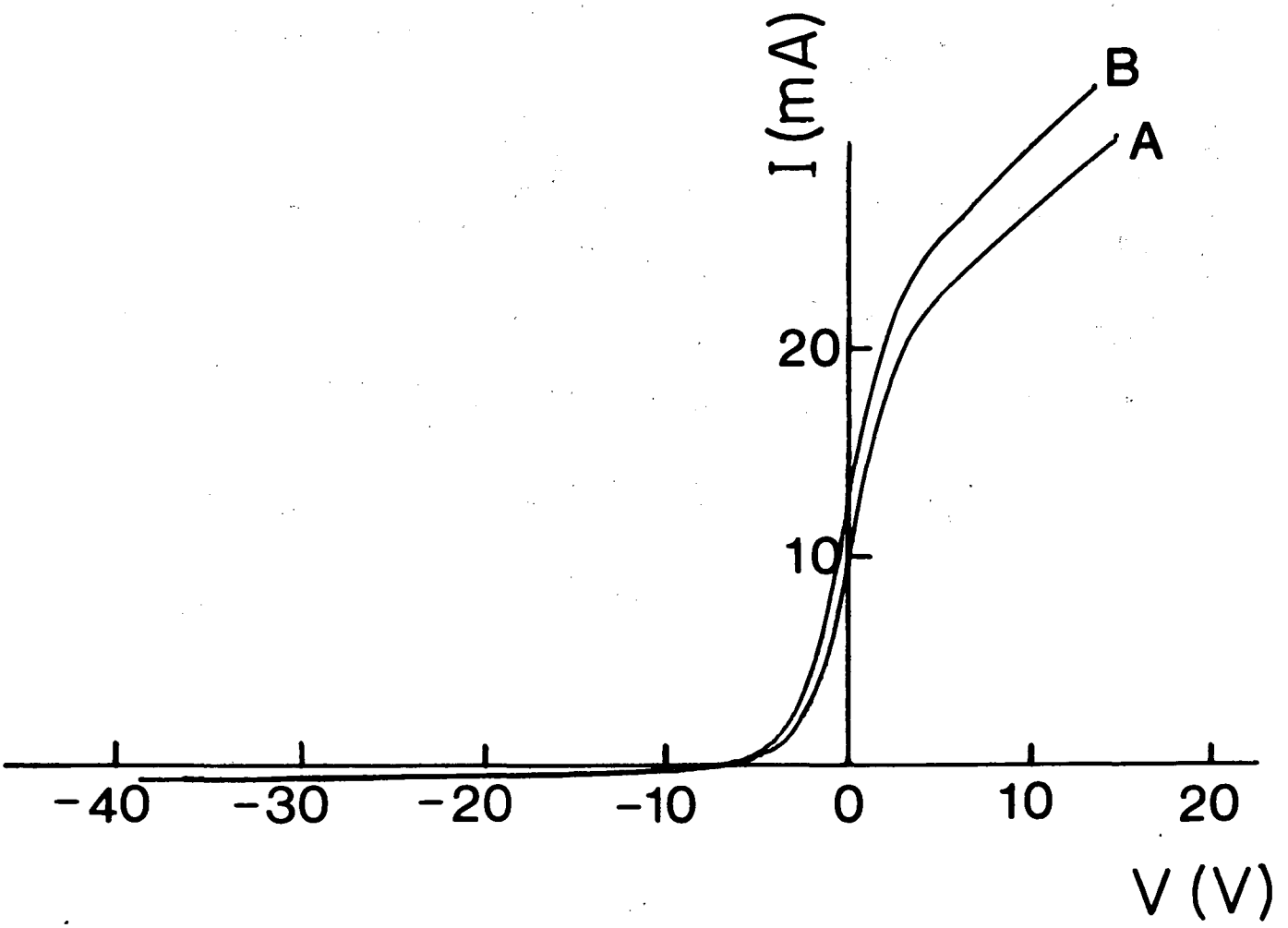


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Fig. 8

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