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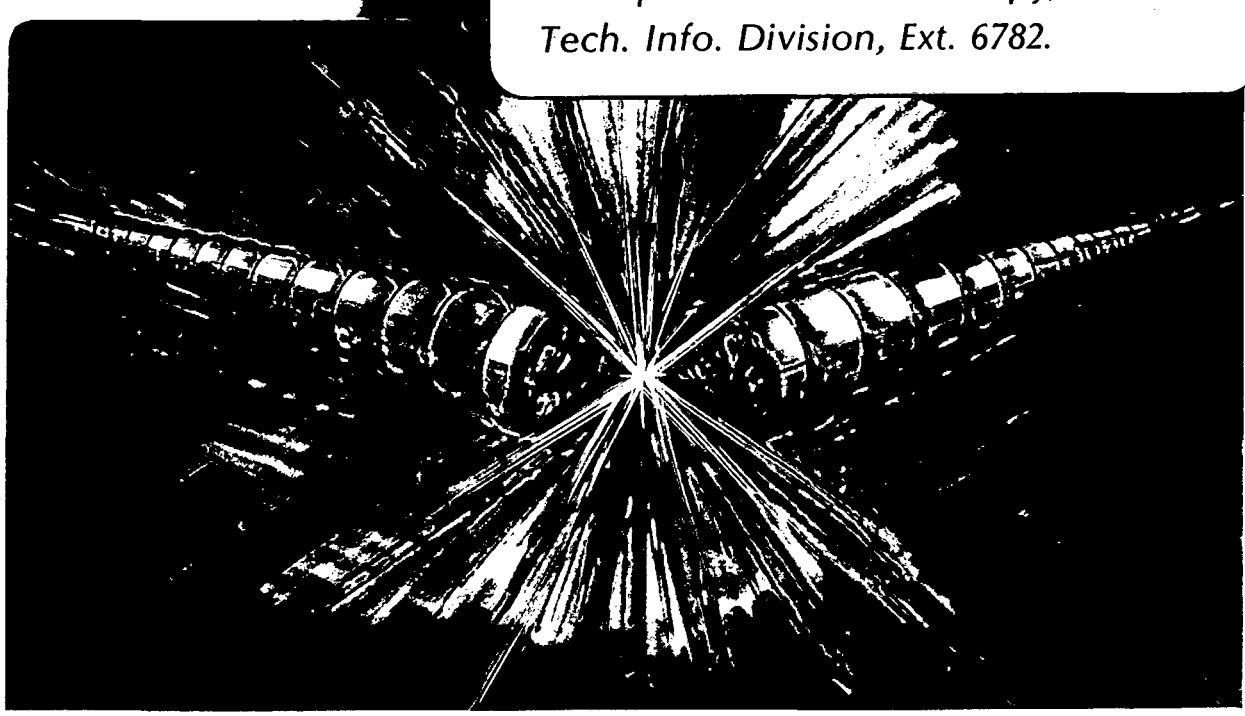

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A High Concentration H_2^+ or D_2^+ Ion Source *

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Abstract

The characteristics of a multicusp source that can produce H_2^+ or D_2^+ ion fraction greater than 80% is described.

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Introduction

Neutral beam injection has proven to be an effective way to heat plasmas in tokamaks as well as mirror devices.[1,2] Multi-amperes of neutral atoms have already been obtained from deuterium ions for energies as high as 120 keV.[3] In some future fusion reactors, such as the Mirror Fusion Test Facility (MFTF-B) at Livermore, high currents of lower energy (40 keV) deuterium atoms are required in certain neutral beam lines.[4] In that respect, it is more advantageous to form the neutral atoms from the molecular D_2^+ ions and accelerate them to twice the energy (80 keV). In passing through the gas neutralizer, these D_2^+ ions will first dissociate and will then be neutralized to form two atomic particles with half the original D_2^+ ion energy. However, this technique is useful only if ion sources that can generate high percentage (> 70%) of D_2^+ ions are available.

In this paper, we describe a novel method of generating a high concentration of H_2^+ or D_2^+ ions by using a modified multicusp ion source. The basic principle in achieving a high percentage of H_2^+ or D_2^+ ions is to extract them from the source as soon as they are produced. Otherwise they will react with background gas molecules to form tri-atomic ions H_3^+ or D_3^+ or be dissociated by electrons. The former reaction $H_2^+ + H_2 \rightarrow H_3^+ + H$ can have a very short mean free path length λ. Assuming a background neutral gas density of 3.3×10^{13} cm^{-3} and a cross-section $\sigma = 6 \times 10^{-15}$ cm^2,[5] $\lambda = (n_o \sigma)^{-1}$ is estimated to be about 5 cm. Thus the distance traversed by the H_2^+ ion before it arrives at the extractor electrode cannot exceed this value. This in turn sets a limit on the length of the source chamber.

Experimental Setup

The experiment was performed in a 2.8 liter stainless-steel chamber (20 cm diam by 9 cm long) with the open end enclosed by a two grid ion extraction system. The first or plasma grid was masked down to a small (0.15×1.3 cm^2) extraction slot in order to reduce the gas loading and the current drawn by the high voltage accel power supply. By mounting samarium-cobalt magnets externally on the chamber, the source could be converted into a multicusp generator as illustrated in Fig. 1. Primary electrons were emitted from four 0.05-cm-diam tungsten filaments and the entire chamber wall together with the plasma grid served as the anode for the discharge.

To extract positive ions, the source and the plasma grid were biased at +300 V or higher and the second grid was connected to ground. A compact magnetic-deflection mass spectrometer[6] located just downstream from the extractor was used to measure the ion species distribution of the small extracted beam.

During normal operation, the 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. The plasma density profile in front of the plasma grid was obtained by a movable Langmuir probe.

Experimental Results

The source was first operated without permanent magnets surrounding

the chamber. In this configuration, it was difficult to obtain a discharge from the four filaments even at extremely high source pressures ($> 10^{-2}$ Torr). Ten columns of samarium-cobalt magnets (1.3 cm wide by 1.9 cm high) were then installed on the outer surface of the source chamber. In addition, four rows of the same size magnets were mounted on the end flange to complete the line cusps. Thus, the source became essentially a short multicusp generator[7] but with the filaments located quite close to the plasma grid.

Figure 2 shows the magnetic field component B_θ measured between two magnet rows on the end flange as a function of the axial position. Since the primary electrons ($E \approx 80$ eV) are reflected at regions where B_θ equals approximately 20 G, the axial length of the plasma volume is only about 2 cm. With the new arrangement, it was found that a hydrogen discharge could be started only with the plasma grid connected to the anode. Since the side-walls and the end flange were mostly shielded by the permanent magnet dipole-field, the plasma grid became the main anode for the discharge. However, the source could now be easily operated even at pressures as low as 10^{-4} Torr.

Figure 3(a) shows a typical spectrometer output signal when the source was operated with a discharge voltage of 80 V and a discharge current of 10 A. It can be seen that 82% of the extracted beam is made up of H_2^+ ions. The percentages of H^+ and H_3^+ ions are about the same ($\sim$ 10%).

Figure 4 shows a plot of the hydrogen ion species distribution as a function of the discharge current I_d. As I_d is increased from 1 A to 23 A, the percentage of H_2^+ ions remains almost constant at 80%. Source operation with higher I_d was limited by the number of filaments available and the high power loading on the plasma grid, which was not water-cooled. The

extractable ion current density is about 50 mA/cm^2 at I_d = 25 A.

It was also observed that the amount of extracted current was a function of the discharge voltage V_d. For a fixed source pressure and discharge current I_d, Fig. 5 shows that the extracted current peaks around V_d = 80 V, but there was no significant change in the species distribution for the range of V_d considered.

Figure 6 shows the ion species distribution for three different pressures. In general, the lower the source pressure, the higher will be the H_2^+ ion percentage. As the pressure outside the source was varied from 8×10^{-5} Torr to 2×10^{-4} Torr, the H_2^+ ion concentration dropped from 86% to 68%. On the other hand, the extracted current increased with the pressure but saturated at about 1×10^{-4} Torr.

Most of the discharge current was collected at the plasma grid and therefore it was the main anode for the discharge. As this electrode was electrically isolated from the remainder of the source chamber (Fig. 1), it was possible to bias the source chamber together with the end flange positive with respect to the plasma. The effect of this magneto-electrostatic containment scheme is to reduce the ion loss to this portion of the chamber, resulting in an increase in the overall efficiency of the ion source.[8] By biasing the source chamber and the end flange +15 V relative to the plasma grid, it was found that the extracted ion current was increased by about 30%. Only a small decrease in the H_2^+ ion fraction (about two percentage points) was observed for a range of I_d.

The plasma density profile across the extraction area (7×7 cm^2) was measured by a movable Langmuir probe. Figure 7 shows a plot of the saturated electron current as a function of the radial position in front of the plasma grid. The result does demonstrate that the profile was reasonably uniform

within the extraction region.

The depth of B-field penetration from the permanent magnets on the end flange was varied by replacing the four rows of large samarium-cobalt magnets with five rows of much smaller (cross-sectional area = 4.5 x 4.5 mm^2) samarium-cobalt magnets. The B_θ component measured between two rows is shown in Fig. 2. Since the 20 G boundary was now located at 4.5 cm from the extractor, some of the H_2^+ ions produced would travel a longer distance before arriving at the extraction grid.

Figure 3(b) shows a spectrometer output signal obtained at V_d = 80 V, I_d = 10 A and at a pressure of 1 x 10^{-4} Torr measured outside the source. Comparing with the data shown in Fig. 3(a), the H_2^+ fraction has been reduced to 71% and the H_3^+ ion concentration has increased to 22%. This observation clearly demonstrates that a short plasma volume is essential for achieving a high percentage of H_2^+ ion in the beam. Figure 8 shows a plot of the species distribution for this new magnet arrangement as a function of discharge current. As I_d is increased from 1 A to 10 A, the H_2^+ ion fraction remains essentially constant at about 72%. When I_d is greater than 10 A, the H_2^+ ion percentage starts to decrease while the H_3^+ ion percentage begins to increase.

The source was also operated with a deuterium plasma using the large samarium-cobalt magnets on the end flange. Figure 9 shows a spectrometer output signal for V_d = 80 V and I_d = 10 A with an outside source pressure of 7 x 10^{-5} Torr. Again, the D_2^+ ion is the dominant species and its concentration in the beam exceeds 80%. In addition to the three deuterium ion peaks (D^+, D_2^+ and D_3^+), two other peaks also appear in the spectrum. They are the deuterium-hydrogen ions (DH^+, D_2H^+) which are formed when the deuterium reacts with the residual hydrogen left in the source chamber.

Work will continue to scale the source operation up to higher discharge power so as to study the species distribution at higher current densities. The sizable amount of heat loading on the plasma grid due to bombardment by electrons and to radiation from the nearby hot filaments will eventually require active cooling of the grid-rails, particularly for the case of long pulse operation. Because the source can be operated at pressures lower than a mTorr, it should be possible to feed gas into the source chamber from the neutralizer region. These together with the design of the magnet configuration of the end flange will require some careful consideration for the development of an intense, high concentration D_2^+ or H_2^+ ion source.

Acknowledgments

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Figure Captions

Fig.1 Diagrammatic drawing of a short multicusp ion source.

Fig.2 A plot of the magnetic field component B_θ, measured between two magnet rows on the end flange, as a function of the axial position.

Fig.3 Spectrometer output signal showing the distribution of hydrogen ion species for a discharge voltage of 80 V and a discharge current of 10 A when the end flange is covered by (a) four rows of large samarium-cobalt magnets, and (b) four rows of small samarium-cobalt magnets.

Fig.4 Hydrogen ion species distribution is shown as a function of the discharge current I_d. The corresponding ion current density measured at the extraction plane is also presented in the figure.

Fig.5 The extracted ion current as a function of the discharge voltage for a fixed source pressure and discharge current.

Fig.6 Hydrogen ion species distribution as a function of source pressure obtained at a discharge voltage 80 V and a discharge current of 10 A.

Fig.7 A plot of the species distribution as a function of the radial position in front of the plasma grid.

Fig.8 Hydrogen ion species distribution as a function of the discharge current I_d when the end flange is covered with four rows of small samarium-cobalt magnets.

Fig.9 Spectrometer output signal showing the ion species distribution when the source is operated with a deuterium plasma.

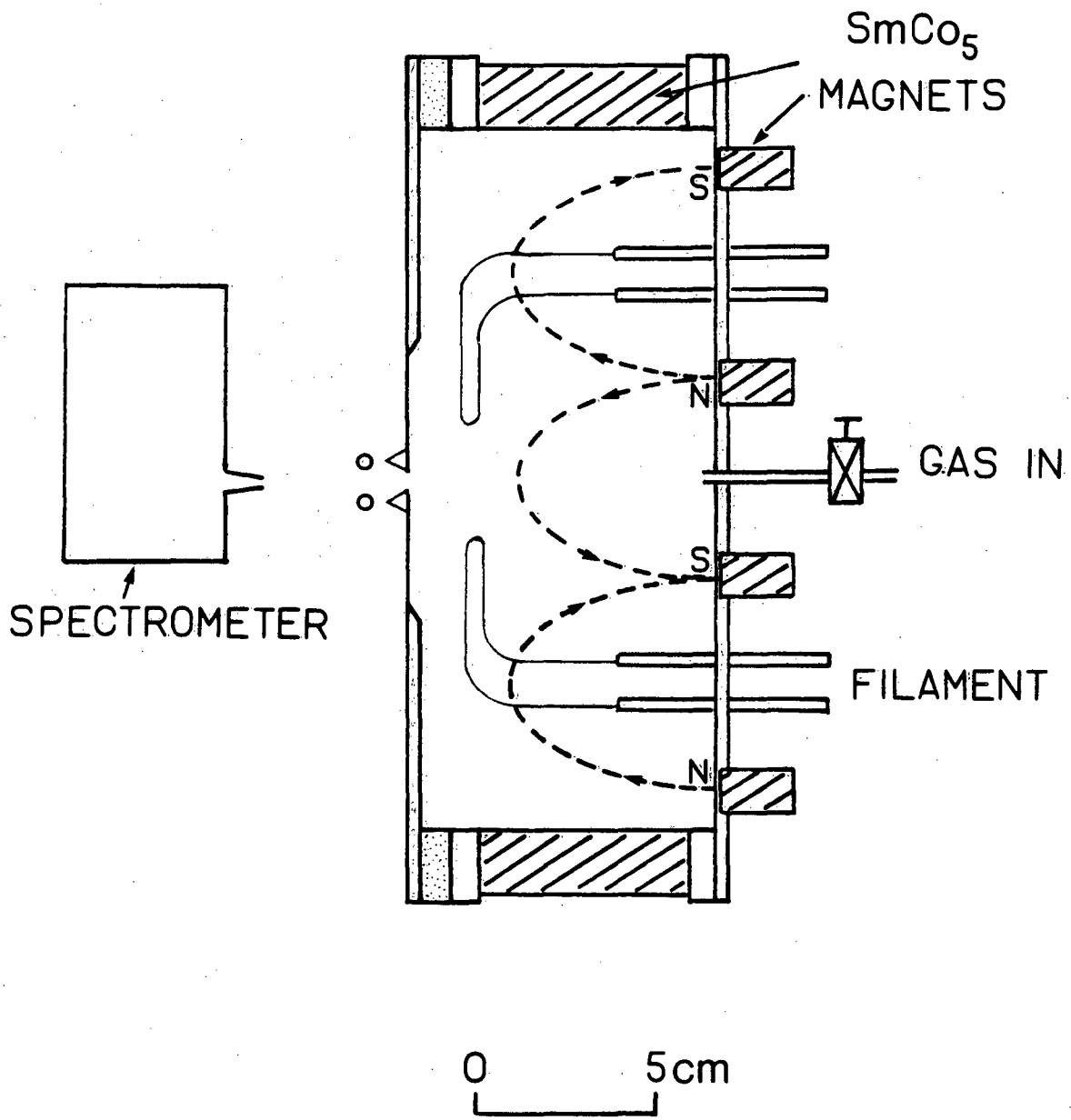

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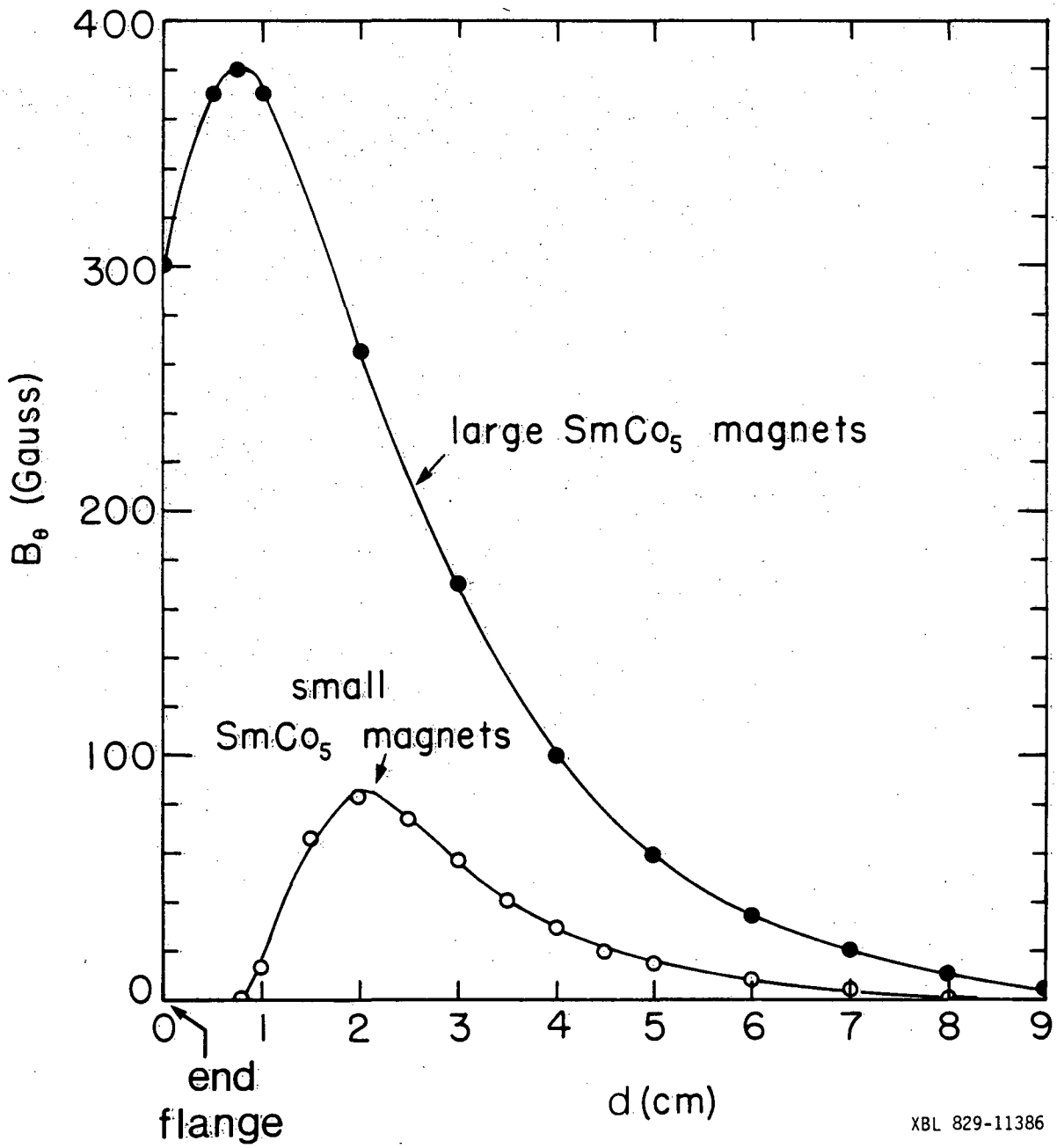
Fig. 1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300
200
100
0
B_θ (Gauss)
large $SmCo_5$ magnets
small
$SmCo_5$ magnets
0
1
2
3
4
5
6
7
8
9
end
flange
d (cm)
XBL 829-11386

Fig. 2

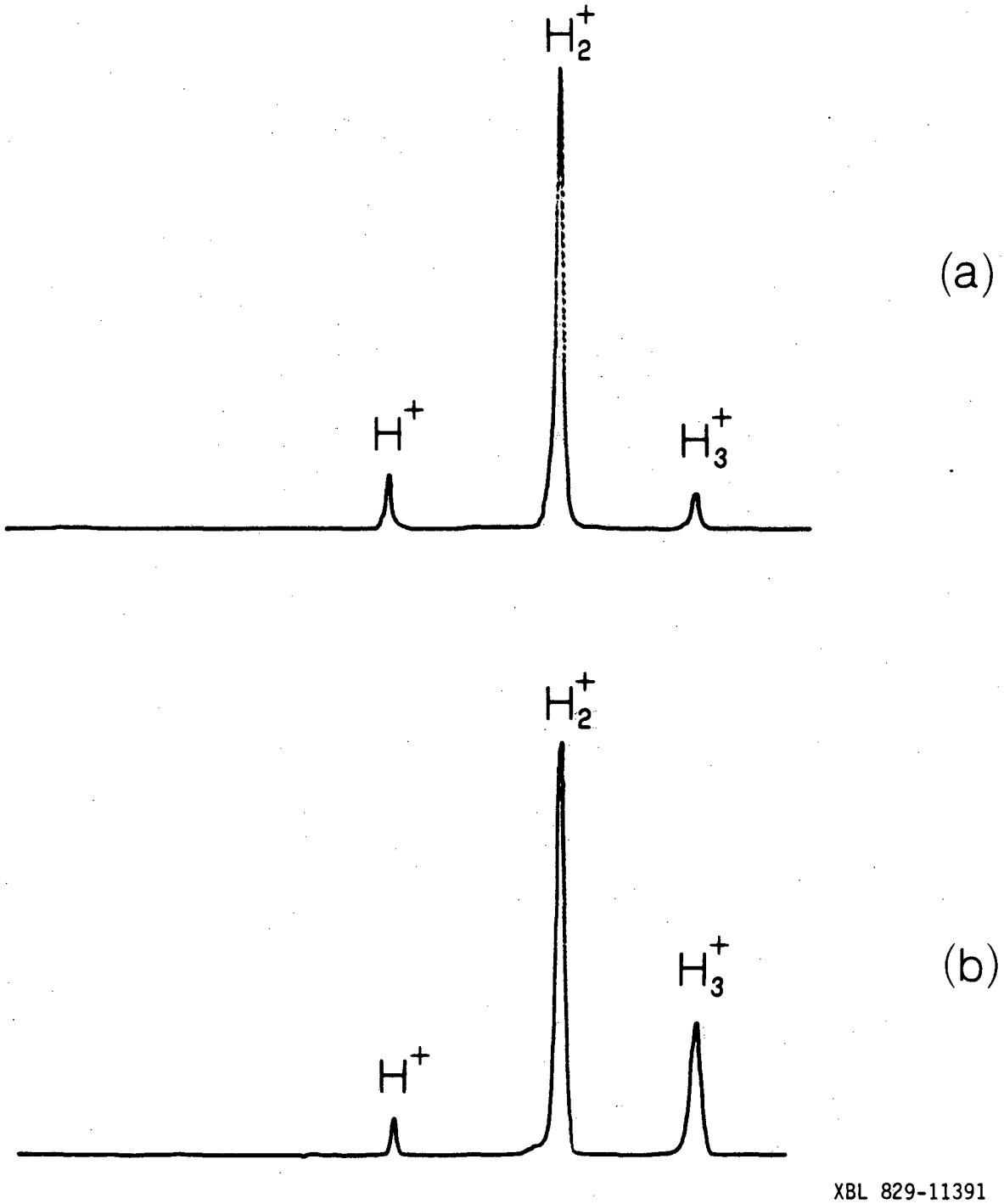
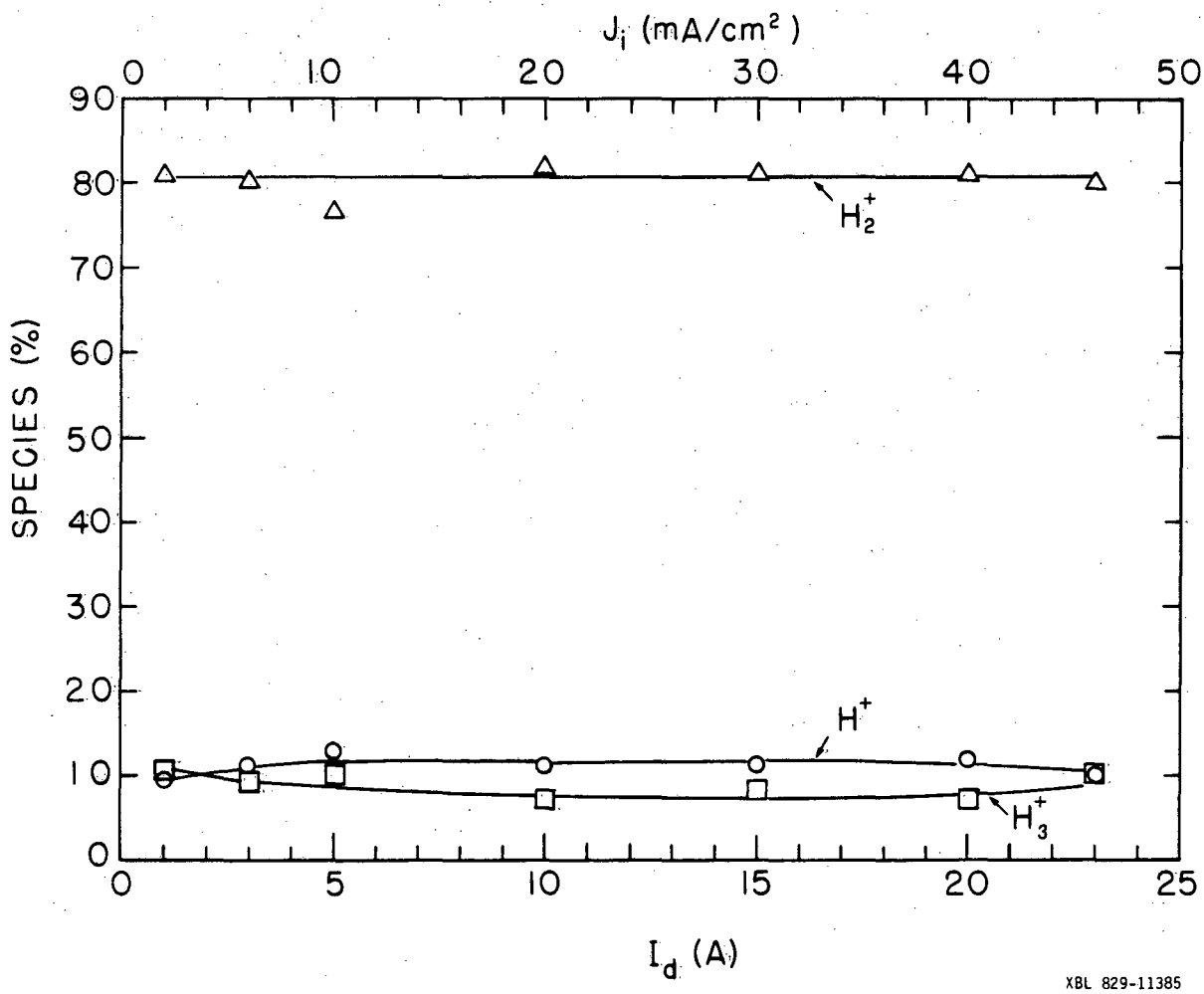


Fig. 3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0
10
20
30
40
50
90
80
70
60
50
40
30
20
10
0
SPECIES (%)
H_2^+
H^+
H_3^+
0
5
10
15
20
25
I_d (A)
XBL 829-11385

Fig. 4

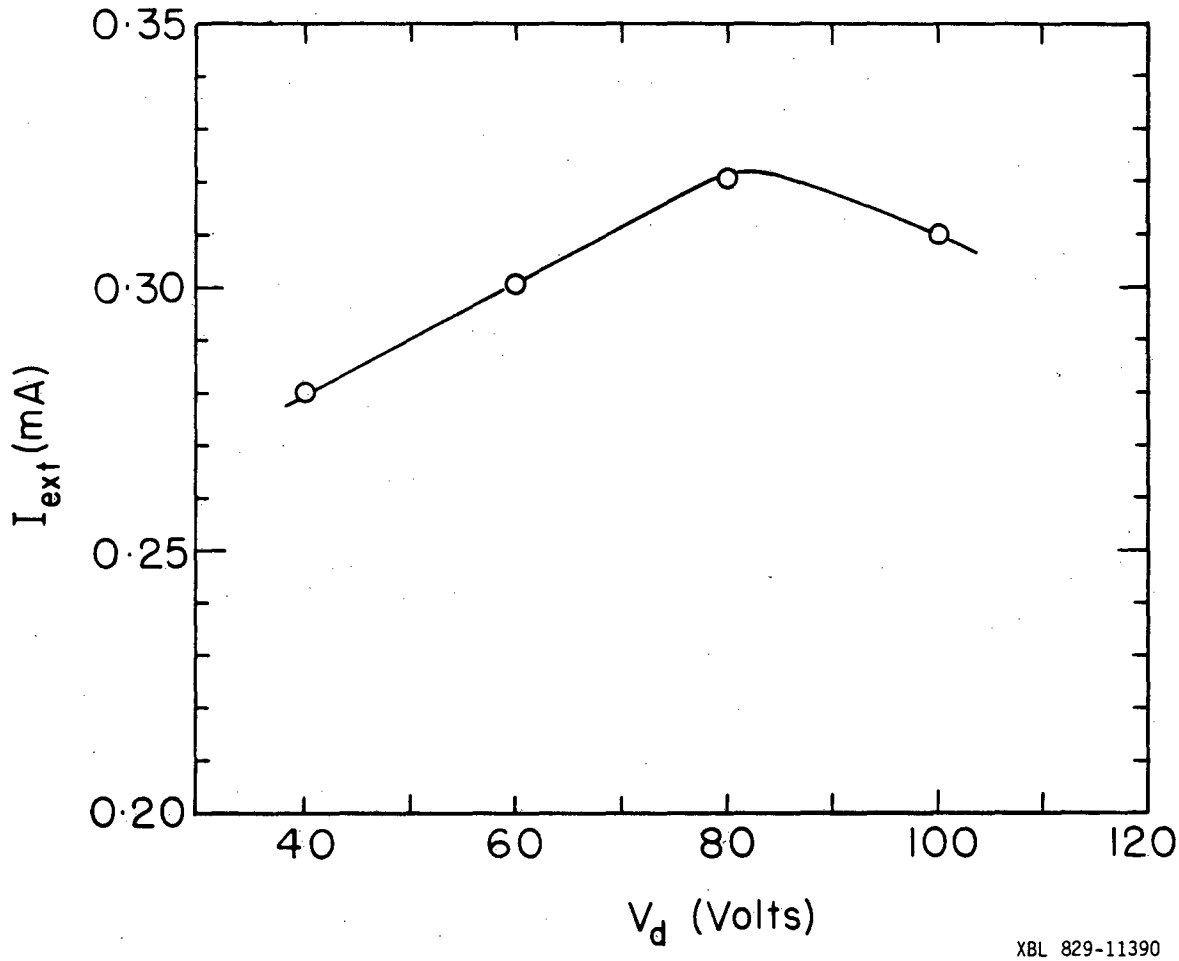

Fig. 5

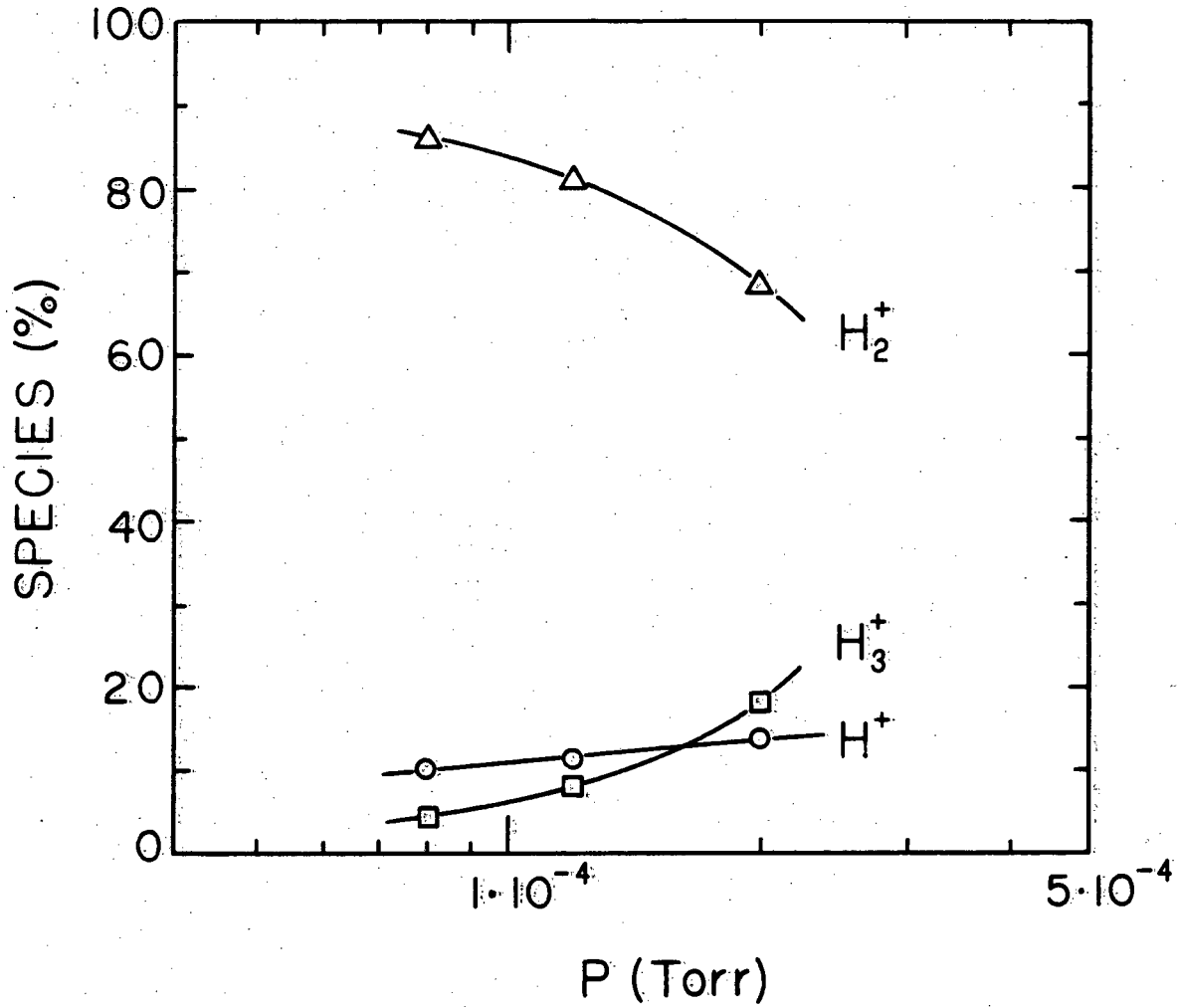

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Fig. 6

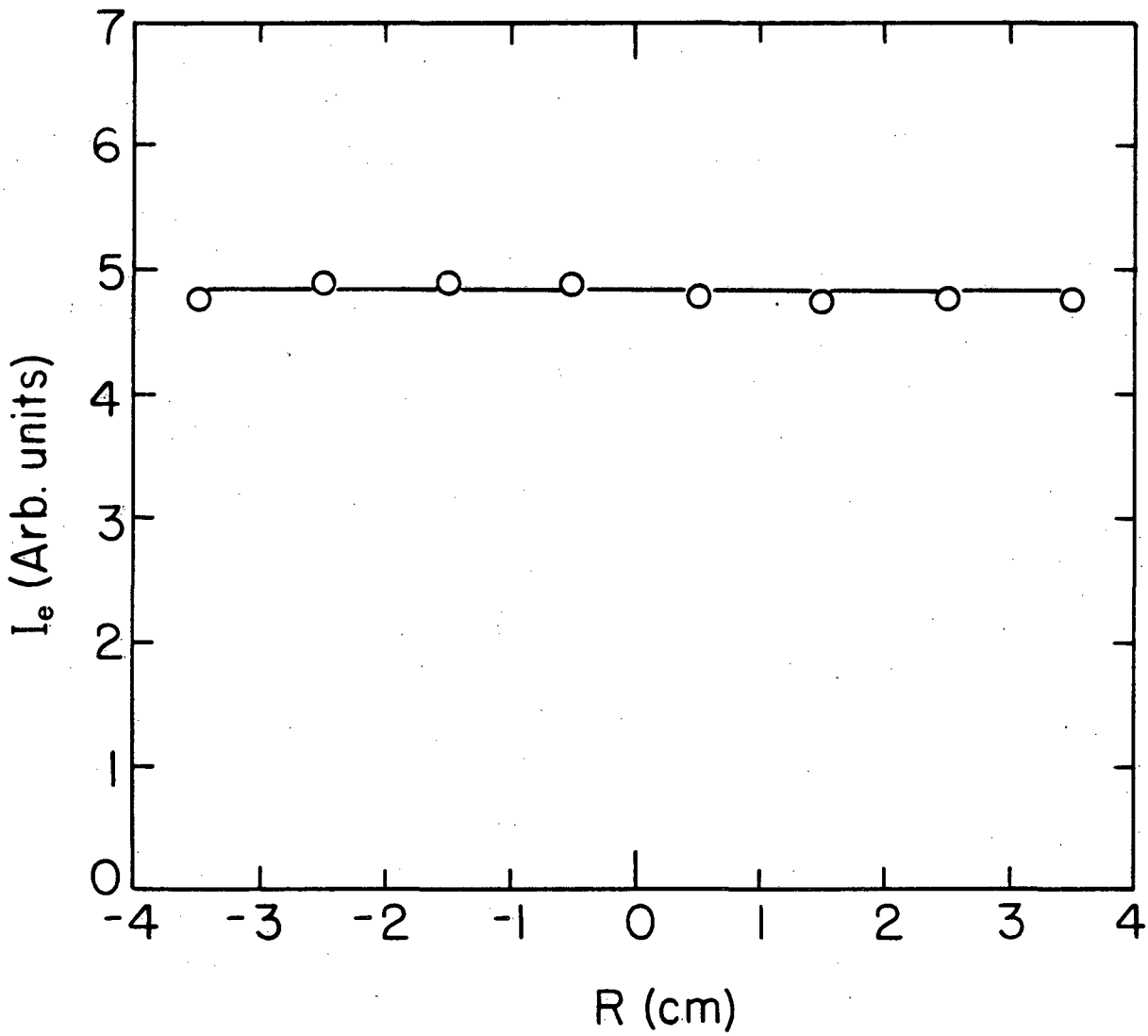

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Fig. 7

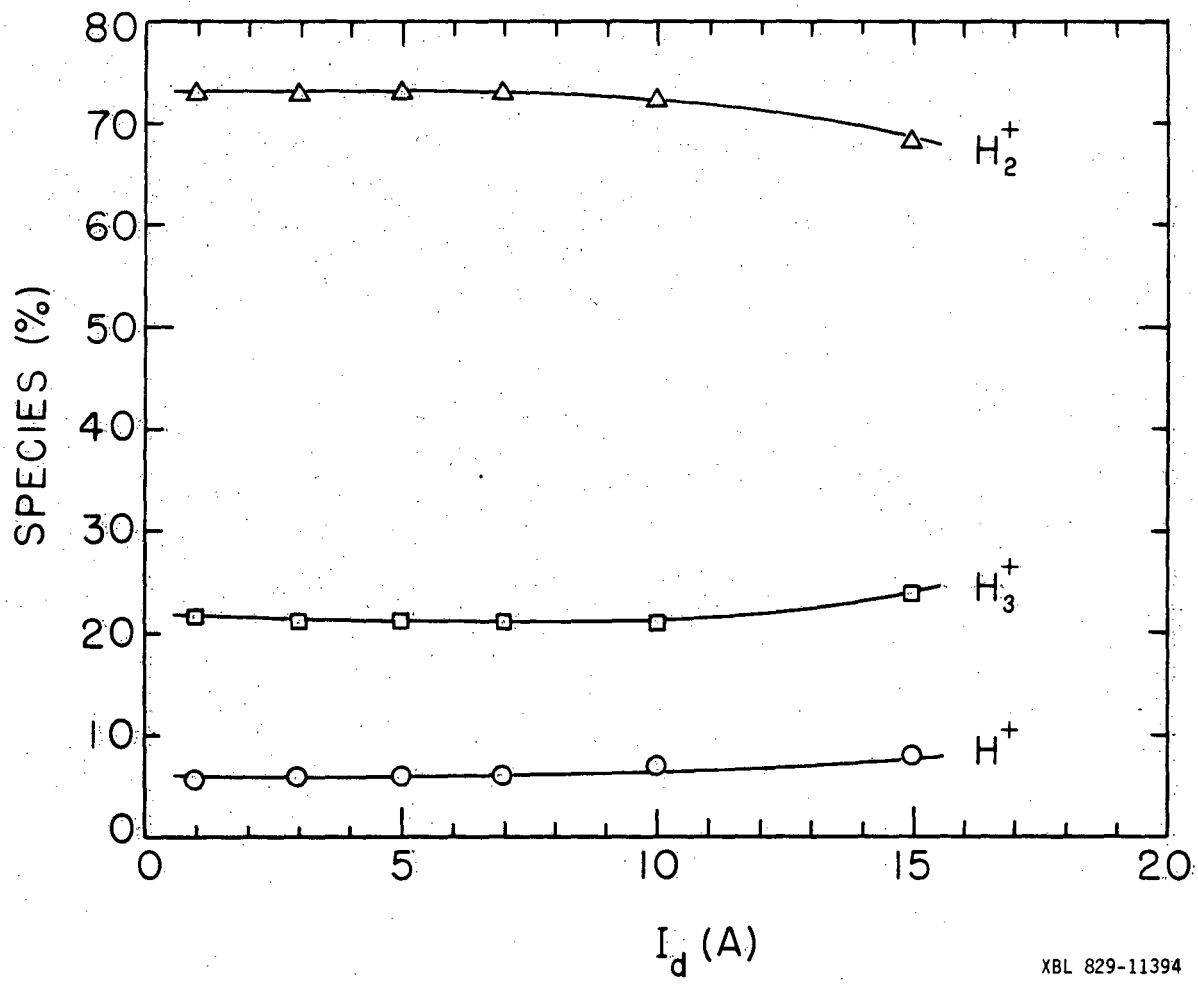
80
70
60
50
40
30
20
10
0
SPECIES (%)
0
5
10
15
20
I_d (A)
H_2^+
H_3^+
H^+
XBL 829-11394

Fig. 8

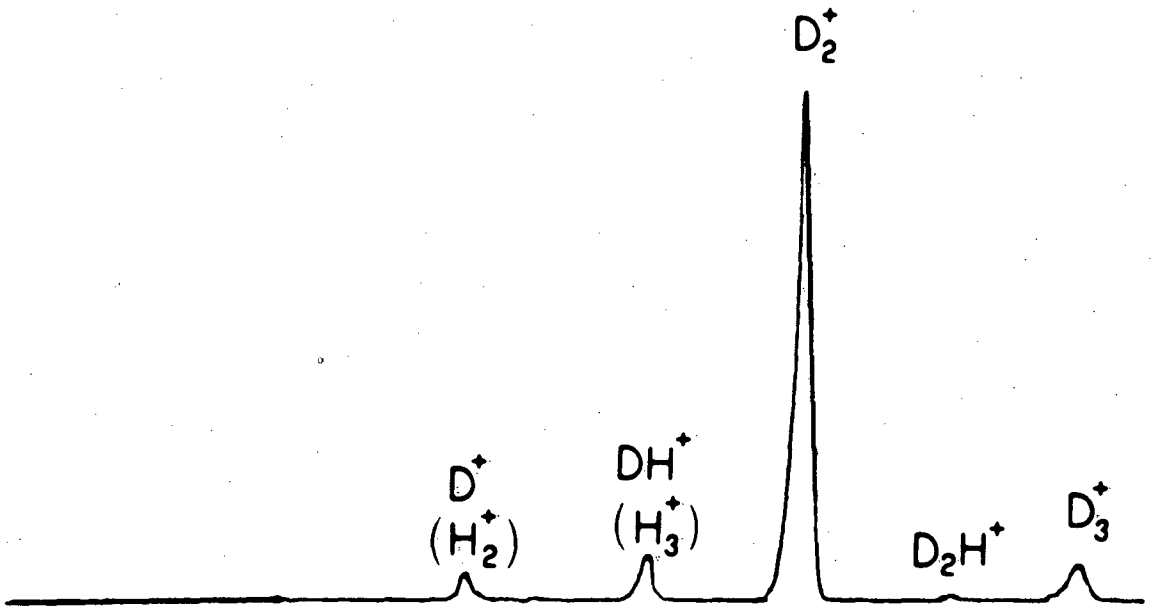

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Fig. 9

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