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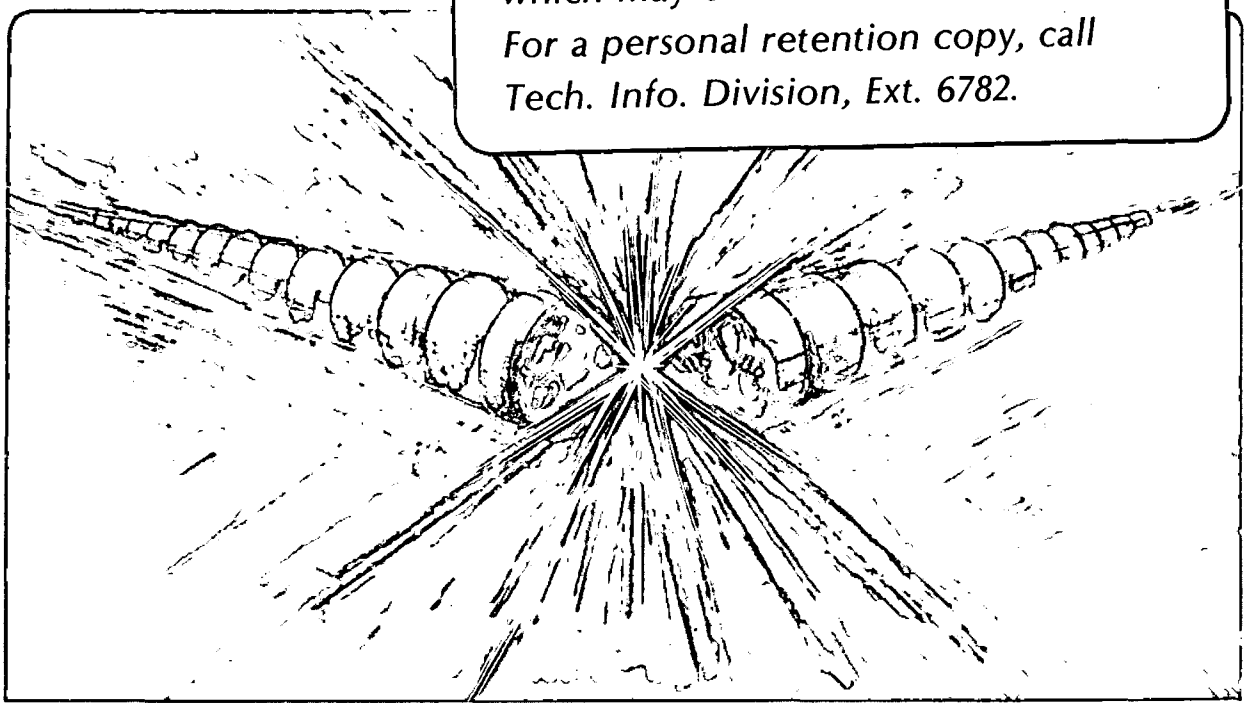

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LBL-14385

Increasing the Efficiency of a Multicusp Ion Source*

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Abstract

The characteristics of a multicusp ion source are compared for two types of permanent magnets. A technique for reducing the ion loss to the regions between the line-cusps is described. The effect of this magneto-electrostatic containment scheme is shown to increase the overall efficiency of the ion source.

* This work is supported by the Director, Office of Fusion Energy, Development & Technology Division, of the U. S. Department of Energy under Contract No. DE-AC03-76SF00098.

Introduction

The permanent magnet generated multicusp (bucket) plasma source is capable of producing large volumes of uniform and quiescent plasma with densities exceeding 10^{12} ions/c.c.[1,2] Experimental results indicate that the large increase in density in this type of source is mainly due to the confinement of the primary ionizing electrons by the dipole fields of the magnets.[2] The containment of ions, however, is found to be much weaker.[3] Plasma can be lost to the line cusps and to regions in between the cusps.

In this paper, we demonstrate that the source efficiency can be improved by employing stronger cusp fields. It is found that the source efficiency increases more than 30% when ceramic magnets are replaced by samarium cobalt magnets. When the source is operated with plasmas such as argon or xenon, there can be a substantial ion loss to areas in between the line cusps. We have succeeded in reducing this ion leakage by installing strips of electrode in between magnet columns. When these electrodes are biased positively with respect to the anode, they reflect the positive ions back to the plasma volume, resulting in an increase of plasma density. The application of this magneto-electrostatic plasma containment scheme enables the density of a xenon plasma to increase by approximately 23%, while the total power increases by only 9%. This technique involves no geometric perturbation to the plasma and should make the multicusp source geometry useful for the generation of the heavy ions used for plasma etching, ion machining and ion implantation purposes.

I. Experimental Apparatus

A schematic diagram of the experimental setup is shown in Fig. 1. The ion source is a water-cooled cylindrical stainless-steel chamber (20 cm diam by 28 cm long) with one end enclosed by a three-grid extraction system. The chamber is surrounded externally by 10 columns of ceramic or samarium cobalt magnets. They form continuous line-cusps parallel to the source axis for primary electrons and plasma confinement.[2] A steady-state plasma is produced by primary ionizing electrons emitted from two 0.05-cm-diam tungsten filaments which are biased at -60 V with respect to the source chamber wall (the anode). In normal operation, the plasma grid of the extractor is left floating electrically and the electron temperature, the density, and the potential of the source plasma are determined by using an axial Langmuir probe.

To study the hydrogen ion species composition, a low energy (~300 eV) ion beam is extracted from the source by means of a standard Berkeley accel-decel electrode system. The extracted beam is then analyzed by a compact magnetic-deflection mass spectrometer[4] located downstream from the extractor.

II. Experimental Results

A. Two different kinds of magnets

The source chamber is surrounded externally by 10 columns of permanent magnets which can be either ceramic ($B_{max} \approx 1.6$ kG) or samarium-cobalt ($B_{max} \approx 3.6$ kG). These magnet columns are separated by 6.3 cm and they all have the same cross-section (1.3 cm wide by 1.9 cm high). In addition, four rows of samarium-cobalt magnets are mounted permanently on the end flange to complete the line cusps.

The source has been operated with four different gases (H_2, D_2, Ar and Xe) with a range of masses. A comparison of the plasma parameters obtained for the two kinds of magnets for a discharge voltage of 60 V and a discharge current of 5 A is presented in Table I. In all cases, as the magnets on the chamber wall were changed from ceramic to samarium-cobalt, the plasma density n at the center of the source increased more than 30%. There is a slight increase in the electron temperature T_e ($\sim$10%) but the plasma potential V_p remains almost unchanged.

The magnetic field components B_r and B_θ measured at the cusps and in between the cusps as a function of the radial positions are shown in Figs. 2 and 3. The values of the B-field components for the samarium-cobalt are about twice that of the ceramic. The increase in source density n is therefore due to the decrease in the effective anode area at the line cusps and also to the reduction of plasma loss to the regions in between the cusps. Since the ion current density J^+ arriving at the plasma grid of the extractor is proportional to the square root of the electron temperature T_e and to the plasma density n at the source center[5], the increase in T_e and n by employing samarium-cobalt magnets will give an average increase of approximately 40% in J^+ for all four plasmas.

B. Biased electrode between cusps.

Previous experiments have shown that permanent magnets can provide only a weak ion containment.[3] In normal operation, the plasma potential at the source center is several volts above the anode potential. Most of the ions produced in the source are lost by acceleration either to the extraction grids or to the chamber walls. It has been reported that electrostatic plugging of plasma leaks at the cusps by a pair of electrodes can increase the source density but at the expense of an equal increase of input power.[6]

Another method to reduce the ion loss to the wall is to make the potential of the source plasma negative with respect to the anode or chamber wall. Such negative plasma potentials have been obtained by the injection of low-energy sub-ionizing electrons into the source plasma.[7] This technique can increase the source efficiency but it requires an extra set of cathodes as well as two additional power supplies.

It has been found that the density of the source plasma depends on the spacing between magnet columns in a multicusp generator and an optimum spacing exists in every device.[2] The optimum appears to be a balance between two competing processes. Most of the loss of primaries and plasma occurs at the cusps. As the magnet separation is increased, the number of columns decreases, thus decreasing the total cusp area. However, as the separation increases, the magnitude of B_θ drops and the loss between cusps increases. The rate of this loss can be substantial if the source is operated with massive ions such as argon or xenon.

An attempt to electrostatically reduce the ion loss to the inter-cusp region has been tried. Ten thin stainless-steel strips (2 cm wide by 27 cm long) were installed inside the source chamber in between the magnet columns as shown in Fig. 4. These strips were electrically isolated from the anode and were connected together by two rings forming an open cage structure as illustrated in Fig. 5. The source was operated with the electrode-strips biased at a potential either negative or positive relative to the chamber wall. No significant change in the source density was observed when a negative bias was applied to the strips. However, a positive bias potential on the electrodes always increased the source density. The strip-electrodes were located in the magnetic field region where the plasma density is much lower than that at the source center. As a result, the electric field generated by

the strips can extend some distance in this weak plasma region. Positive ions that reach the region between the magnet columns will experience the repulsive electric force and will be reflected back into the source plasma. Some electrons are collected by the strips but the electron current is always saturated at a bias voltage of approximately +10 V or less.

Figure 6 is a plot of the electrode current I_b as a function of the bias voltage V_b for a xenon plasma. The total electron current drawn by the strips is about 2.7 A at V_b= +10 V for the case of samarium-cobalt magnets (this current becomes 4.2 A when ceramic magnets are used). As the source is operated with less massive plasma ions, the current I_b decreases. For a deuterium plasma, Fig. 7 shows that I_b saturates at about 1 A and at a lower bias voltage of +5 V.

Table II summarizes the power consumed by the discharge and bias power supplies as well as the plasma parameters obtained when the source is operated with and without the positively biased strips for the case of ceramic magnets. For the hydrogen plasma, the source plasma density n increases by about 11% while only 1.2% of extra power is supplied to the system. The effect of biasing the strip-electrodes on the hydrogen ion species distribution is shown in the mass spectrometer output signal in Fig. 8. It can be seen that as the bias potential V_b is increases from anode potential to +5 V, the molecular ion species H_3^+ increases from 44% to 52%. This result demonstrates that of the three ion species (H^+, H_2^+, H_3^+), H_3^+ has the highest probability to leak out to the inter-cusp region. For the xenon plasma, the density n increases by 27% when V_b = +10 V, but the total input power increases by 14%. There is a small increase in the electron temperature T_e and the plasma potential V_p becomes more positive by 6 volts. The increase in V_p indicates that the confinement of the positive ions has been improved.

Table III shows the effect of this technique when samarium-cobalt magnets are used. With the positively biased strips, the xenon plasma density increases by 23% but the total input power now increases by only 9%. Notice that there is no significant change in density n, electron temperature T_e and plasma potential V_p for the hydrogen and deuterium plasmas. This result demonstrates that the B_θ component of the samarium-cobalt magnets is already strong enough to contain most of the hydrogen and deuterium ions.

The use of this magneto-electrostatic containment scheme involves no geometric perturbation of the plasma, but offers the possibility of using the multicusp plasma source as a heavy ion generator for plasma etching, ion machining and ion implantation purposes. In fact, we have applied this technique to the self-extraction negative hydrogen ion source[8] which is operated with cesium. Figure 9 shows an electrode cage similar to that shown in Fig. 5 installed inside the negative ion source chamber. Since the electrode-strips are thermally insulated from the chamber wall, they become hot during the discharge and neutral cesium does not readily adhere to them. A positive bias potential on these strip-electrodes also prevents the Cs^+ ions from reaching the inter-cusp region. The result is a much reduced cesium input requirement as the cesium is confined within the discharge rather than being allowed to condense on the chamber walls. By varying the strip bias potential, the concentration of cesium in the discharge can be optimized, and the H^- ion yield from the source has been increased by about 30%.

Acknowledgments

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8. K. W. Ehlers and K. N. Leung, Rev. Sci. Instrum. 51, 721 (1980).

Figure Captions

Fig. 1 Schematic diagram of the experimental apparatus.

Fig. 2 The measured magnetic field components as a function of radial positions for the ceramic magnets.

Fig. 3 The measured magnetic field components as a function of radial positions for the samarium-cobalt magnets.

Fig. 4 Cross-sectional view of the multicusp ion source showing the strip-electrodes.

Fig. 5 The complete structure of the strip-electrodes.

Fig. 6 The electrode current as a function of the bias voltage for a xenon plasma with a discharge voltage of 60 V and a discharge current of 5 A.

Fig. 7 The electrode current as a function of the bias voltage for a deuterium plasma with a discharge voltage of 60 V and a discharge current of 5 A.

Fig. 8 The spectrometer output signal showing the hydrogen ion species when the strip-electrodes are biased at +5 V and at anode potential with a discharge voltage of 60 V and a discharge current of 5 A.

Fig. 9 The multicusp negative ion source with an electrode cage installed.

Table I. Plasma parameters obtained for two different kinds of magnets with discharge voltage = 60 V and discharge current = 5 A.

Gas	Pressure (Torr)	Ceramic magnets			$SmCo_5$ magnets		
		V_p (V)	T_e (eV)	n (ions/c.c.)	V_p (V)	T_e (eV)	n (ions/c.c.)
H_2	5×10^{-4}	+2.9	1.5	2.45×10^{11}	+2.6	1.8	3.2×10^{11}
D_2	5×10^{-4}	+3.5	1.8	2.5×10^{11}	+3.5	2.0	3.3×10^{11}
Ar	1×10^{-4}	+4.5	2.9	2.7×10^{11}	+4.7	3.35	3.5×10^{11}
Xe	1×10^{-4}	+5.2	2.5	4.5×10^{11}	+4.9	2.8	6.1×10^{11}

Table II. Power supplied to the discharge and to the bias electrodes and the plasma parameters obtained for the case of ceramic magnets.

Gas	Pressure (Torr)	V_d(V)	I_d(A)	P_d(W)	V_b(V)	I_b(A)	P_b(W)	V_p(V)	T_e(eV)	n(ions/c.c.)
H_2	5×10^{-4}	60	5	300	-	-	-	+2.9	1.5	2.45×10^{11}
	5×10^{-4}	60	5	300	5	0.7	3.5	+3.3	1.5	2.7×10^{11}
D_2	5×10^{-4}	60	5	300	-	-	-	+3.5	1.8	2.5×10^{11}
	5×10^{-4}	60	5	300	5	1.1	5.5	+4.3	1.8	2.9×10^{11}
Ar	1×10^{-4}	60	5	300	-	-	-	+4.5	2.9	2.7×10^{11}
	1×10^{-4}	60	5	300	10	3.4	34	+9.8	3.3	3.5×10^{11}
Xe	1×10^{-4}	60	5	300	-	-	-	+5.2	2.5	4.5×10^{11}
	1×10^{-4}	60	5	300	10	4.2	42	+11.2	2.75	5.7×10^{11}

Table III. Power supplied to the discharge and to the bias electrodes and the plasma parameters obtained for the case of samarium-cobalt magnets.

Gas	Pressure (Torr)	V_d(V)	I_d(A)	P_d(W)	V_b(V)	I_b(A)	P_b(W)	V_p(V)	T_e(eV)	n(ions/c.c.)
H_2	5×10^{-4}	60	5	300	-	-	-	+2.6	1.8	3.2×10^{11}
	5×10^{-4}	60	5	300	5	0.1	0.5	+2.7	1.8	3.3×10^{11}
D_2	5×10^{-4}	60	5	300	-	-	-	+3.5	2.0	3.3×10^{11}
	5×10^{-4}	60	5	300	5	0.3	1.5	+3.8	2.0	3.5×10^{11}
Ar	1×10^{-4}	60	5	300	-	-	-	+4.7	3.4	3.5×10^{11}
	1×10^{-4}	60	5	300	10	1.4	14	+7.3	3.4	4.3×10^{11}
Xe	1×10^{-4}	60	5	300	-	-	-	+4.9	2.8	6.1×10^{11}
	1×10^{-4}	60	5	300	10	2.7	27	+9.0	3.2	7.5×10^{11}

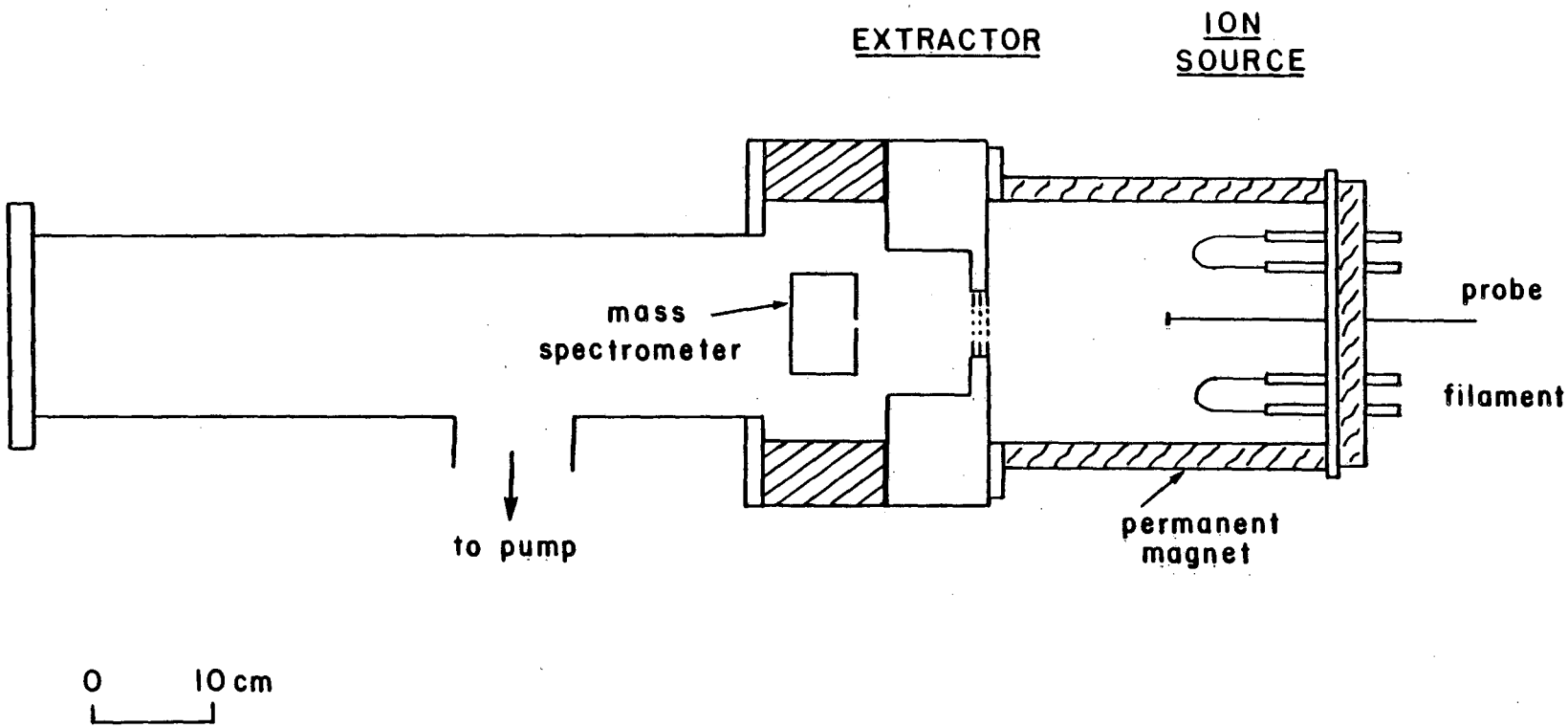

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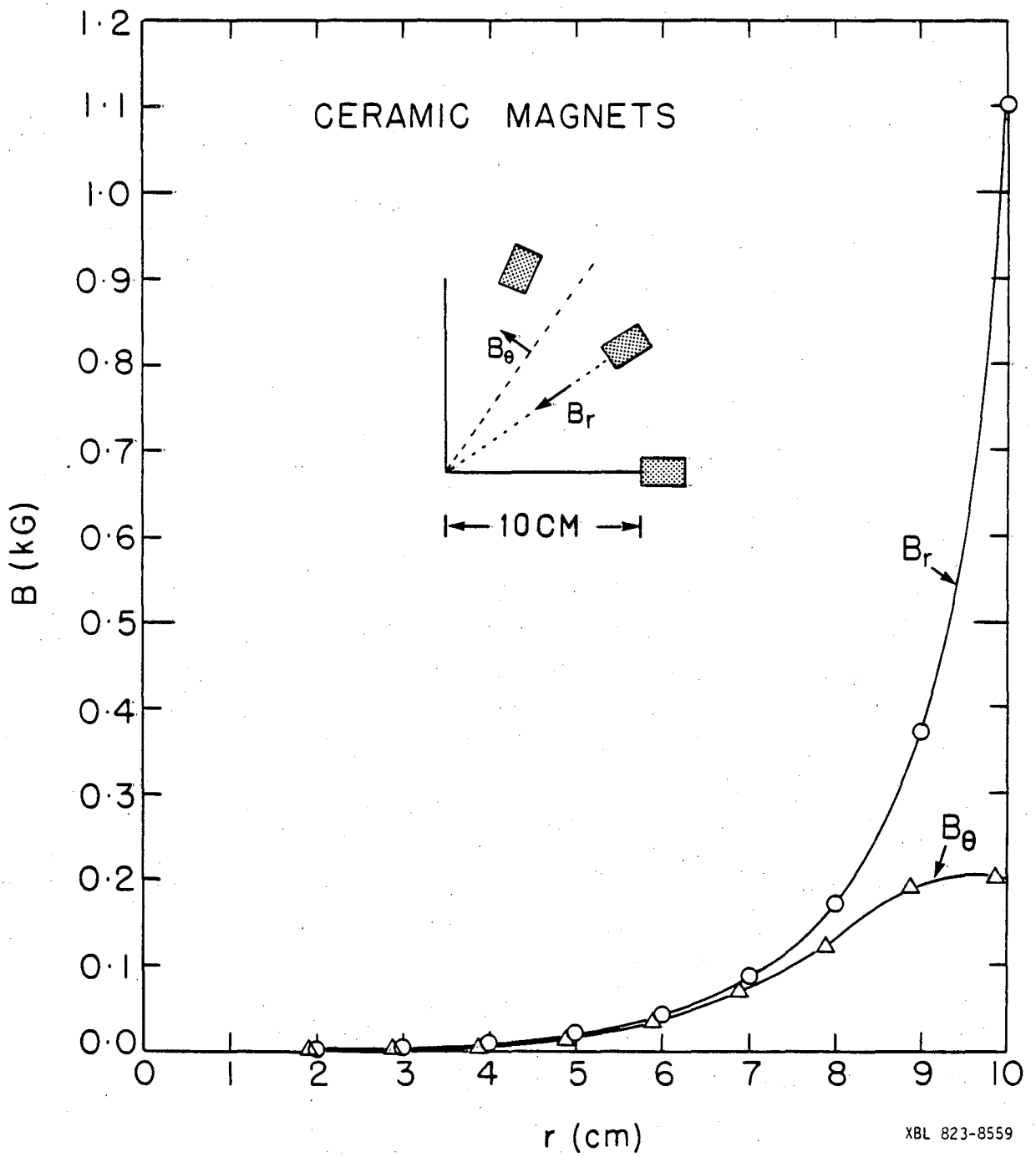
Fig. 1


CERAMIC MAGNETS
B_θ
B_r
10 CM
B_r
B_θ
B (kG)
r (cm)
1·2
1·1
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0·0
0
1
2
3
4
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7
8
9
10
XBL 823-8559

Fig. 2

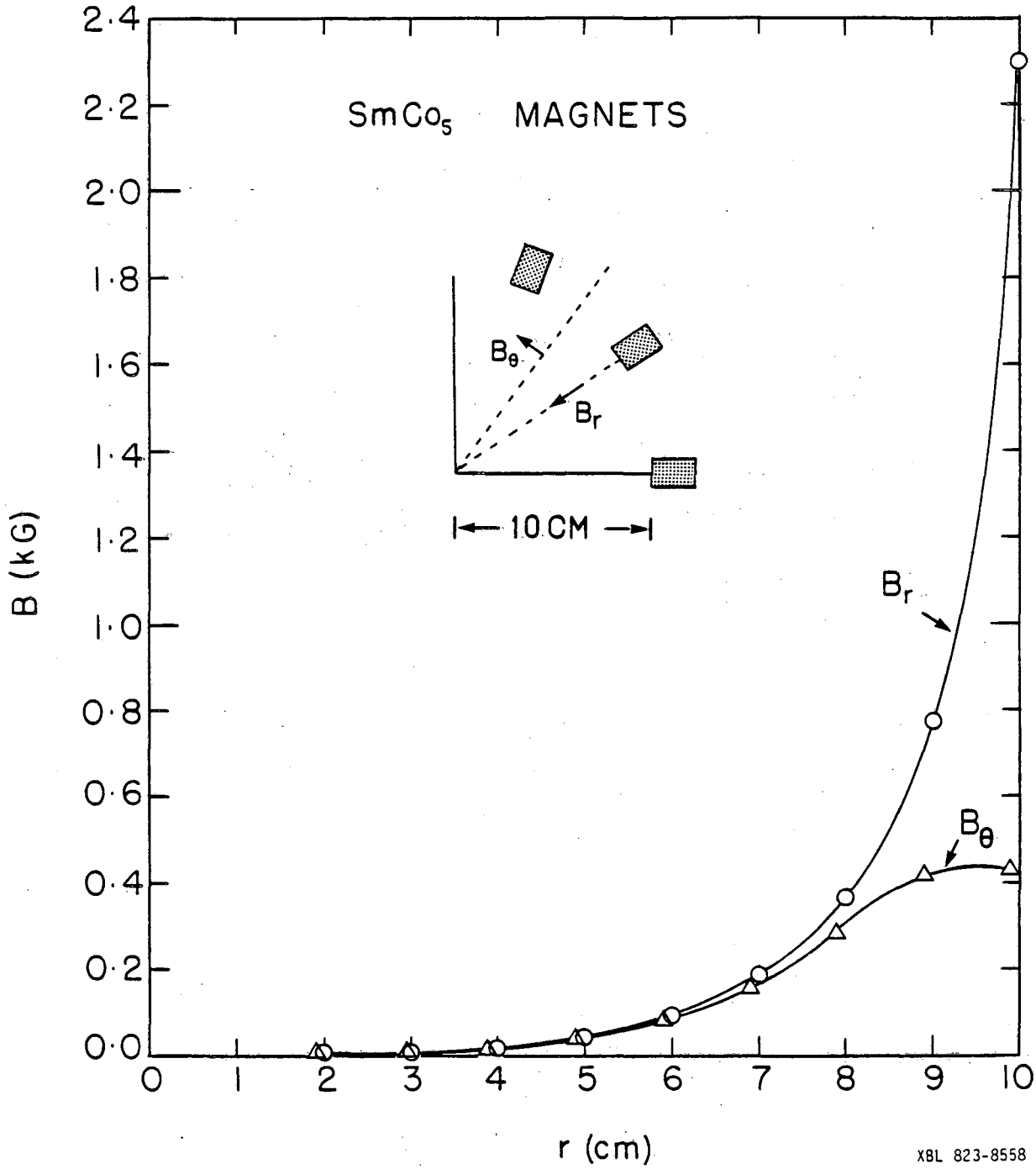
SmCo5 MAGNETS
B (kG)
r (cm)
Br
Bθ
10 CM
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
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Fig. 3

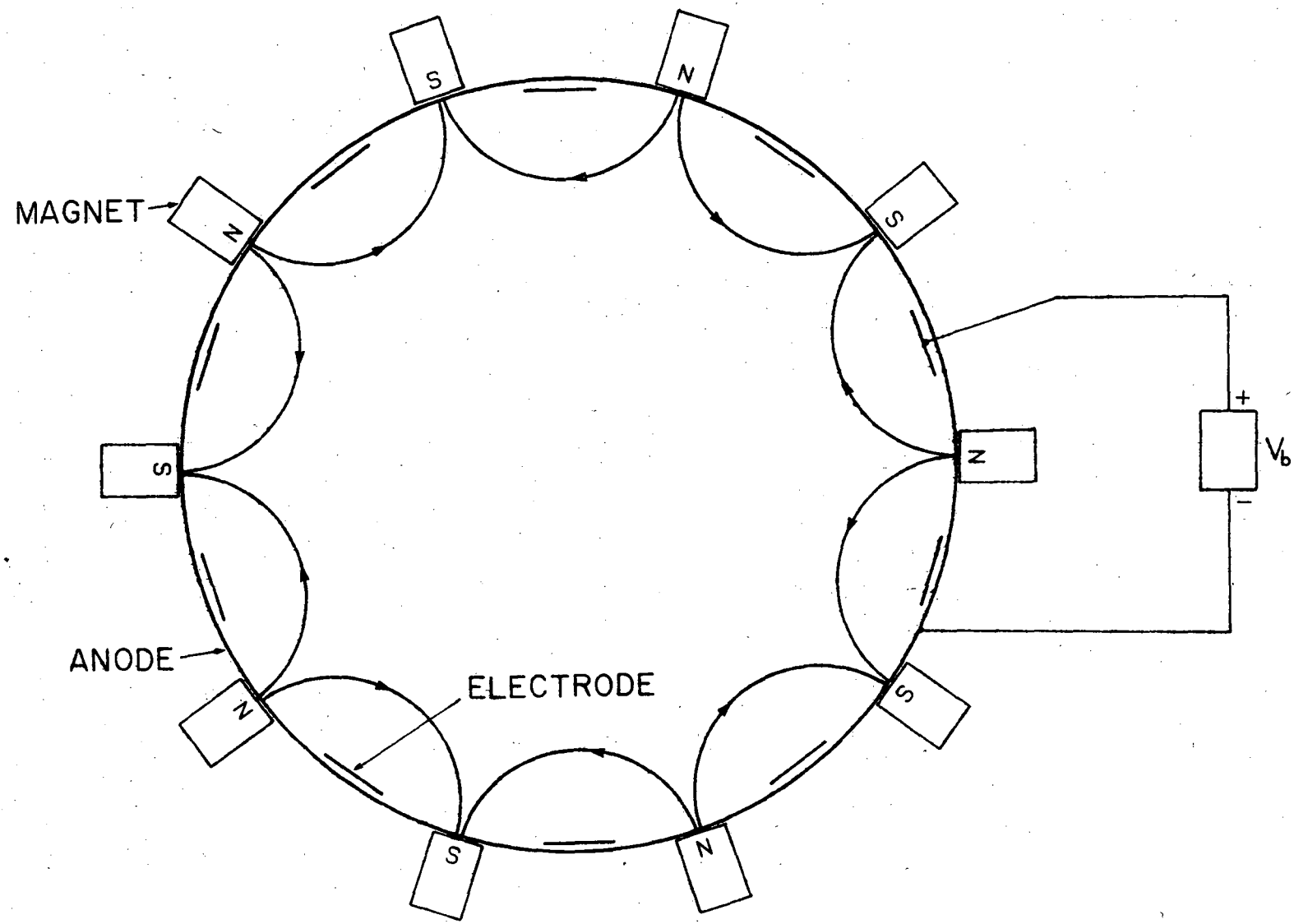

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Fig. 4

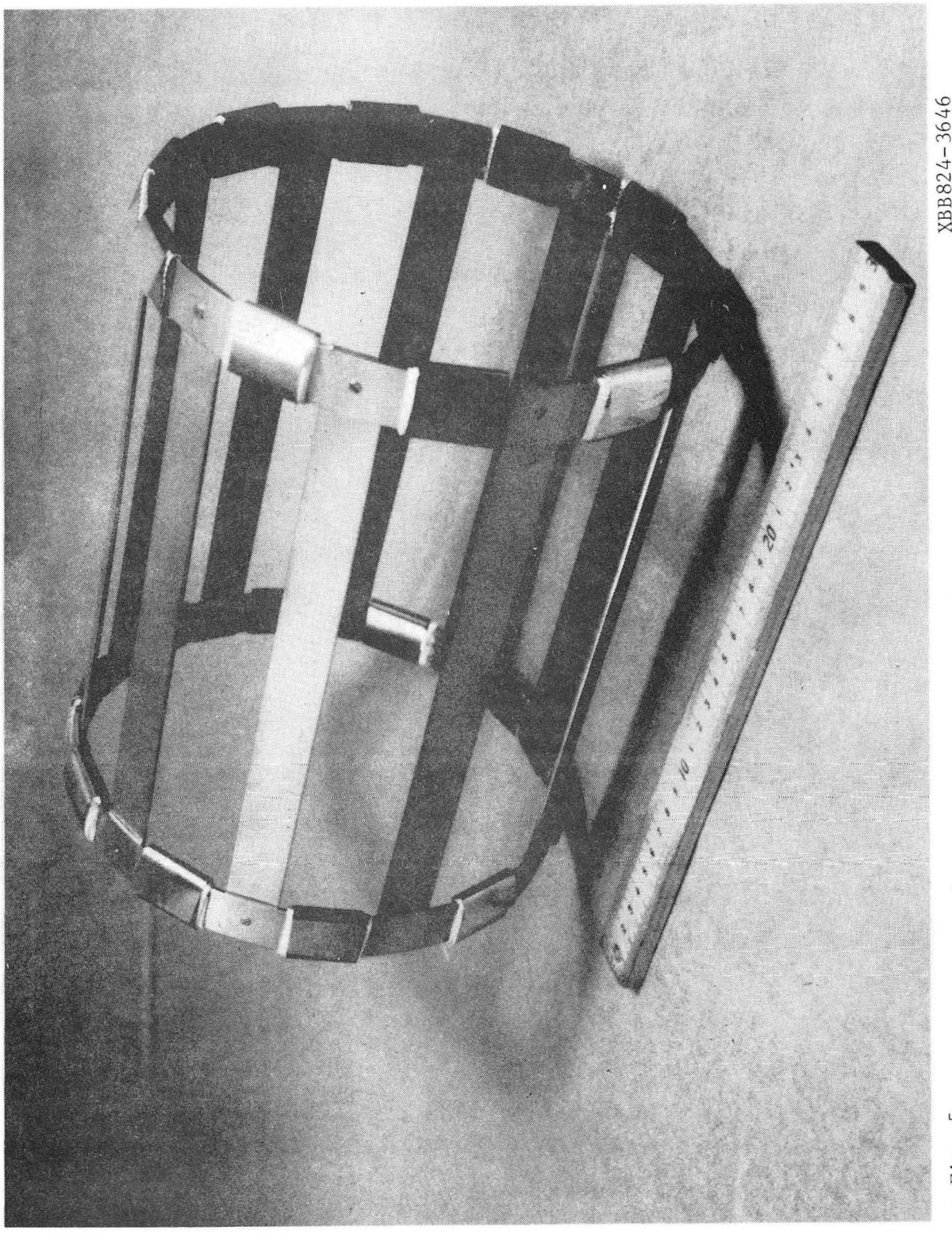

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Fig. 5

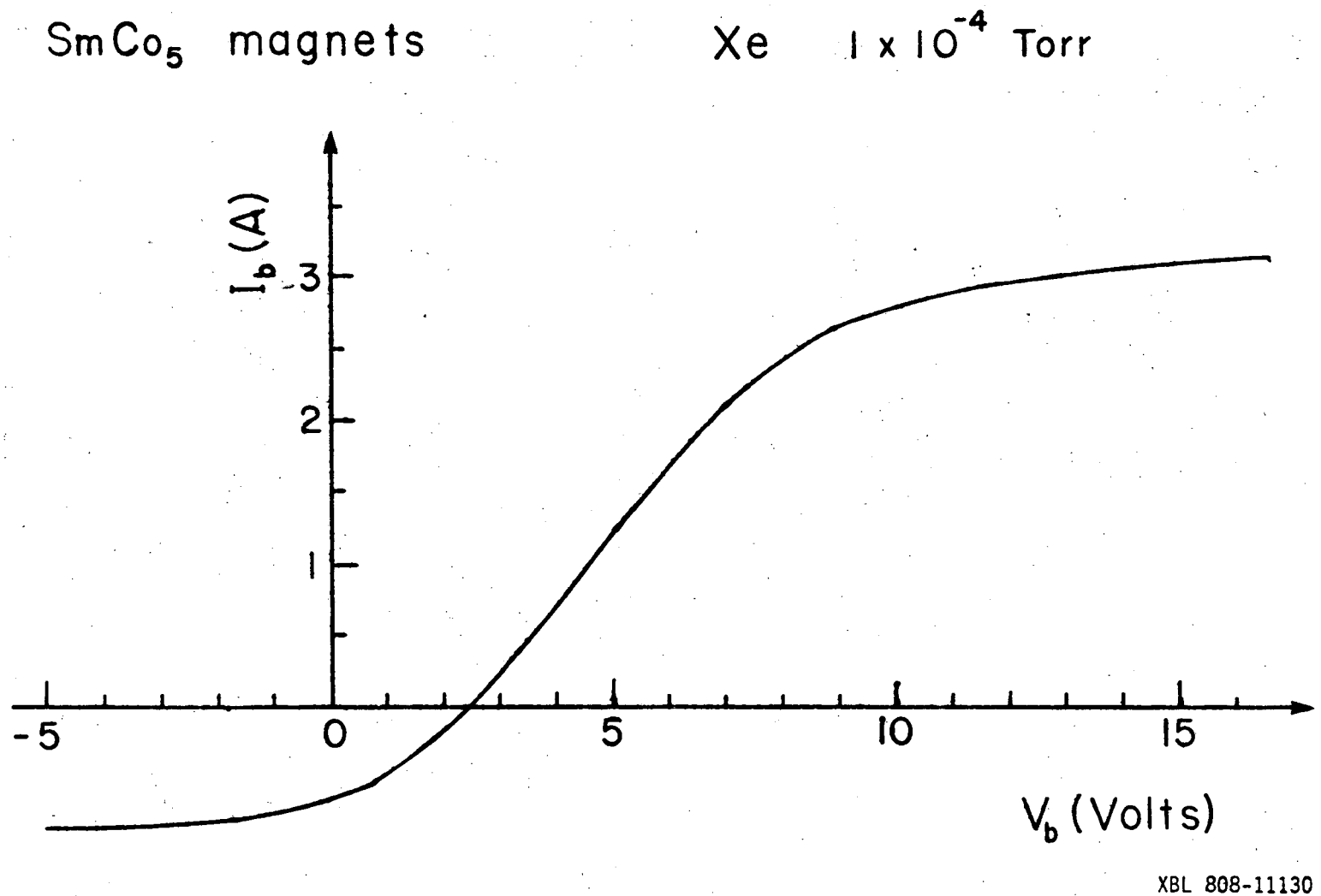
SmCo5 magnets
Xe 1 x 10^-4 Torr
Ib (A)
3
2
1
-5
0
5
10
15
Vb (Volts)
XBL 808-11130

Fig. 6

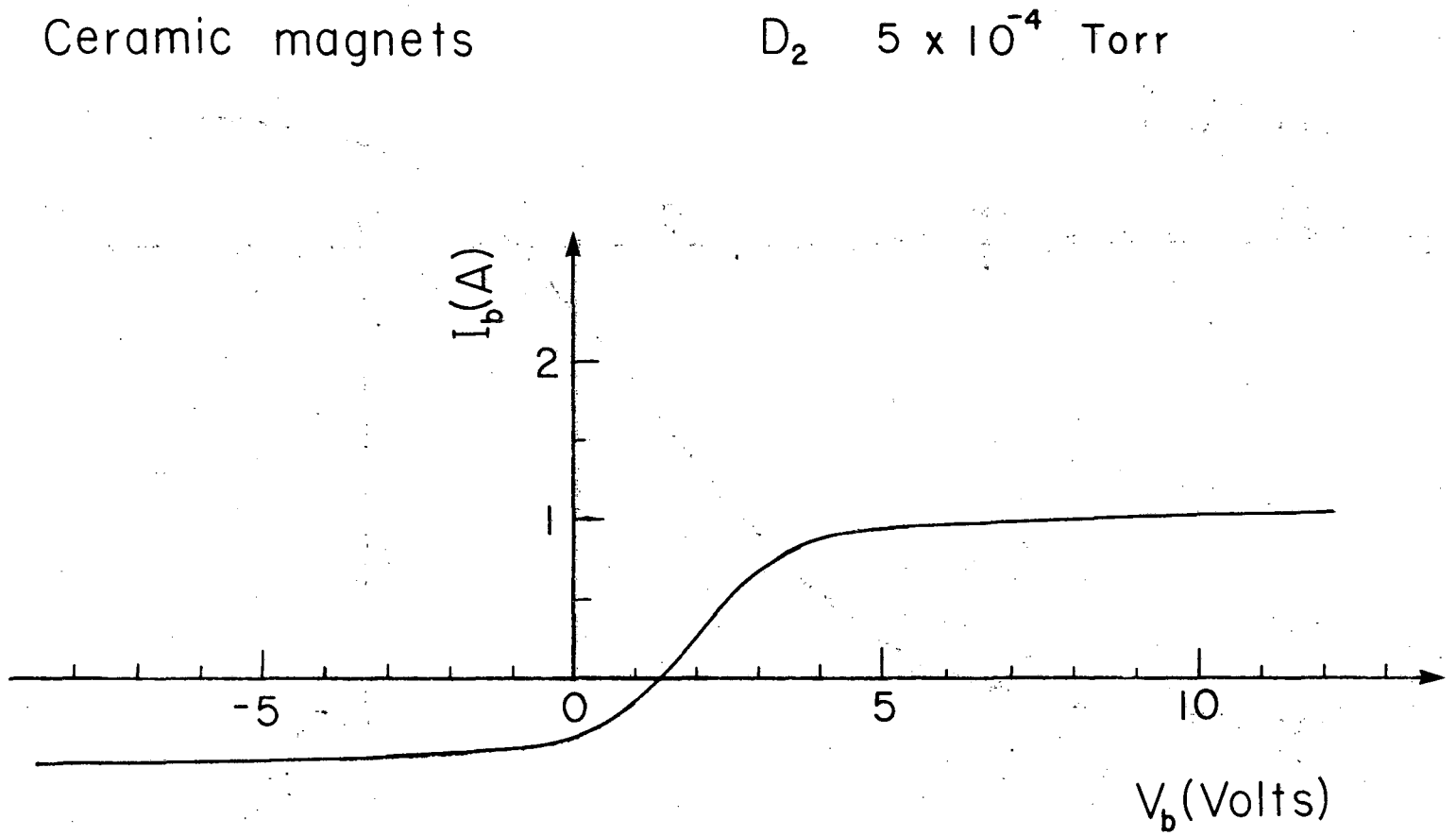

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Fig. 7

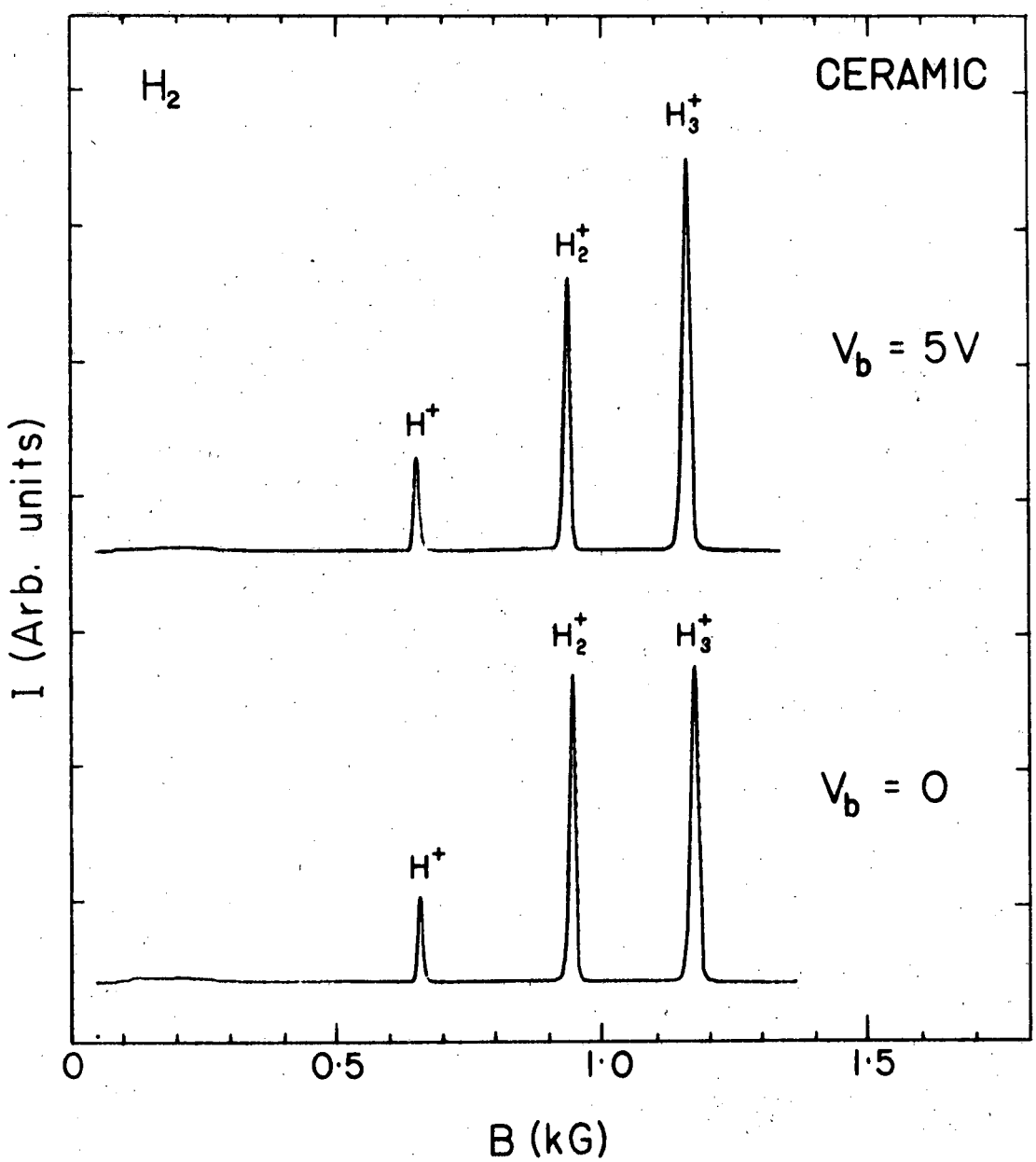

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Fig. 8

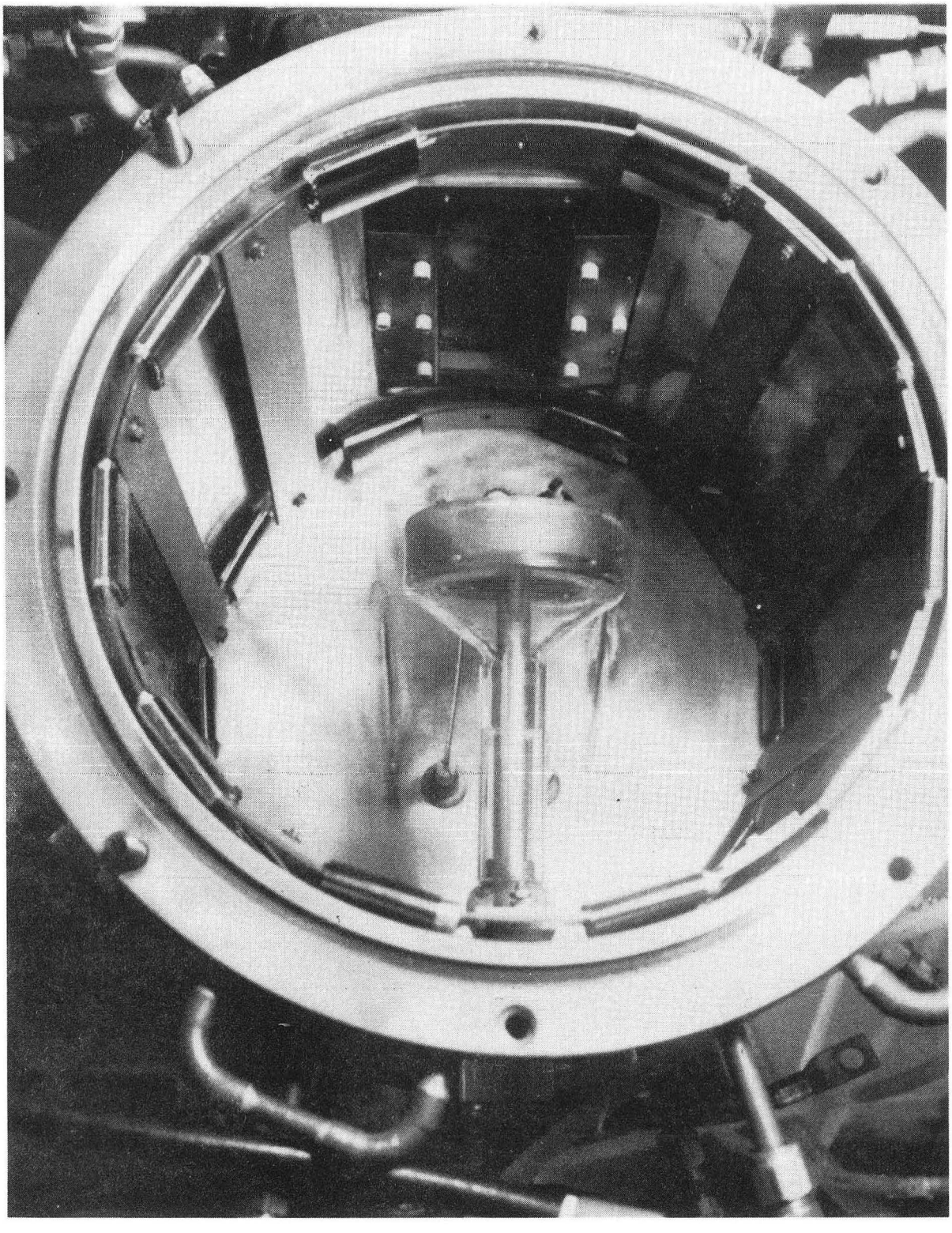

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Fig. 9

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