THE INFLUENCE OF B_θ ON DENSITY DISTRIBUTION IN A TOROIDAL OCTUPOLE

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DISTRIBUTION IN A TOROIDAL OCTUPOLE*

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ABSTRACT

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The effects of the addition of an azimuthal magnetic field to a toroidal octupole field is studied using saturated Langmuir probes to measure ion density. The initial decay of the plasma is observed to be exponential with a lifetime which decreases with increasing B_θ. In the originally unstable region near the walls, some change is seen in the density distribution. With or without B_θ densities are constant along flux surfaces including the high field regions behind the rods. The density is peaked slightly off the separatrix in the direction of the rods with and without B_θ. Oscillations observed in this region of unstable density gradient are reduced by adding shear(B_θ). At late times when the magnetic field is decreasing, the plasma moves out toward the wall inverting the density gradient. Floating potential oscillations of 10 kHz are seen at the position of the late time density inversion.

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INTRODUCTION

A toroidal octupole magnetic field provides a confinement region in which $\oint dl/B$ is a maximum on the separatrix and has minima at the current-carrying hoops and at a critical field line (ψ_c) near the wall (See Fig. 1). The most favorable condition for interchange stability in the region bounded by ψ_c is that the plasma pressure also be a decreasing function away from the separatrix.

The addition of a toroidal field to the poloidal octupole field produces a configuration with magnetic shear. In this case both the resulting equilibrium pressure distribution and the conditions for a stable equilibrium may be changed.

EXPERIMENTAL

A toroidal field of 250 gauss at the outer wall was added to our system, and data were obtained by measuring the ion saturation current to a single Langmuir probe, 1/8" in length by 1/8" in diameter.

Oscillographs of ion saturation current, measured at the center, for the two cases are shown in Figure 2. Initially both signals are of the same order of magnitude and in neither case is there any evidence of a sudden loss of plasma. Semilog plots of the decays are shown in Figure 3. Our injection time is such that the peak of the 5 msec field pulse is at 200 μsec on this graph. For the first 500 μsec the decay rate is greater for the case with a B_θ field added. At about 1 msec both signals begin to decay rapidly due to the decay of the confining fields.

A comparison of the density profiles at various times is shown in Figure 4. These were measured on a vertical line through the center. At about 500 μsec the density at the center is down about 20% with the B_θ added (compare with Figure 3). The shapes of the two curves, however, do not differ much. At about 1400 μsec as the plasma moves out due to the decreasing magnetic field, a reversed density gradient is developed. At the same time the floating potential begins to oscillate in this region. These oscillations have a frequency of about 10 kHz and an amplitude of $\sim$1/4 V (Figure 5).

Figure 6 shows the densities plotted in Ψ space, where Ψ is the flux function labeling field lines from -5 at the rods to +5 at the walls. Scans were made on the three lines shown at the left. The points for the scan on top of the rod, where the field is strongest, are shown with a horizontal error bar indicating the width of the probe in Ψ space. These data show several things: first of all, the density is approximately constant along a field line. So that, as expected for hydromagnetic equilibrium, the pressure gradient is perpendicular to the flux surfaces. In particular, for the separatrix, the density at the top of the rod, where $B \sim 4$ kgauss, is the same order of magnitude as at the center where $B = 0$. Secondly the peak in density is not at the separatrix but is displaced slightly towards the rods. When the B_θ field is added, the shape remains the same and the peak is still displaced towards the rods.

The floating potential in the region between the separatrix and the peak in density is shown in Figure 7. Oscillations of amplitude ~1V and frequency ~250 kHz are present when there is no B_θ. Adding the B_θ field reduced these oscillations. At the maximum B_θ they are almost completely eliminated.

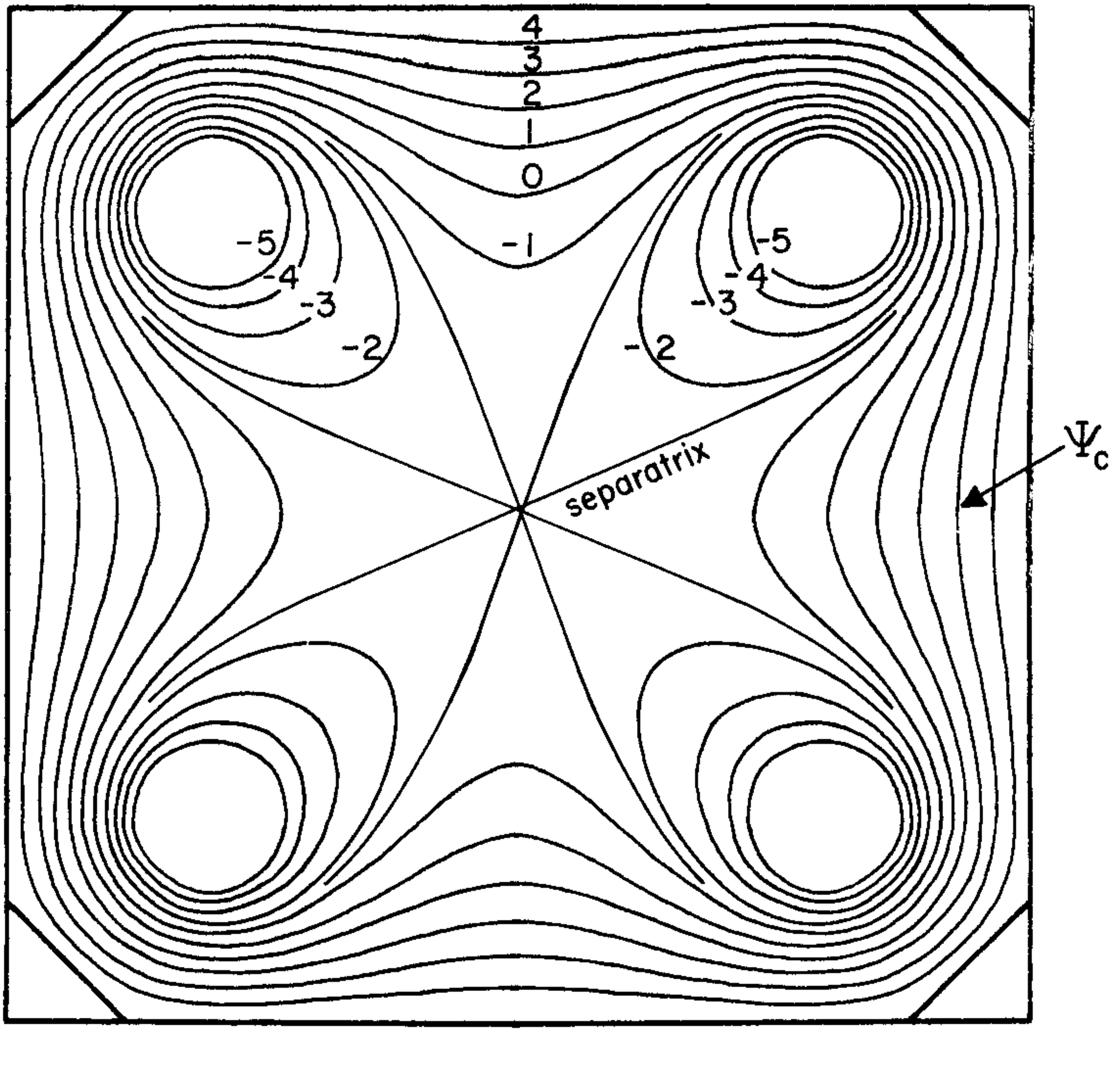
The condition for interchange stability including the finite pressure term can be written in the form:

$$\frac{dE_p}{d\psi} = p'V'' + \gamma\, p \frac{(V'')^2}{V'}$$
$$= pV'' \frac{d}{d\psi} \ln (pV'^{\gamma}) \qquad > 0.$$

Where the derivatives are with respect to Ψ, and V' is the volume of a tube of unit flux. Because of the pressure term an inverse gradient may not be unstable. If we assume the temperature is a constant, then stability is determined by the slope of $\ln (n V'^{\gamma})$ where n is the density. A plot of this function for our plasma is shown in Figure 8. In the region to the left of the separatrix where $V'' > 0$, we have stability. The $p'V''$ term is negative from $\Psi = 2$ to the separatrix but the pressure term dominates here. From the separatrix to Ψ_c, $V'' < 0$, so we again have stability. Outside of Ψ_c, $V'' > 0$ so here we should have a flute unstable region which is in agreement with experimental observations. Also plotted here are the data for the late time density inversion mentioned perviously. In this case the pressure is small and there is a region where the slope begins to invert. This is where the 10 kHz floating potential oscillations are seen.

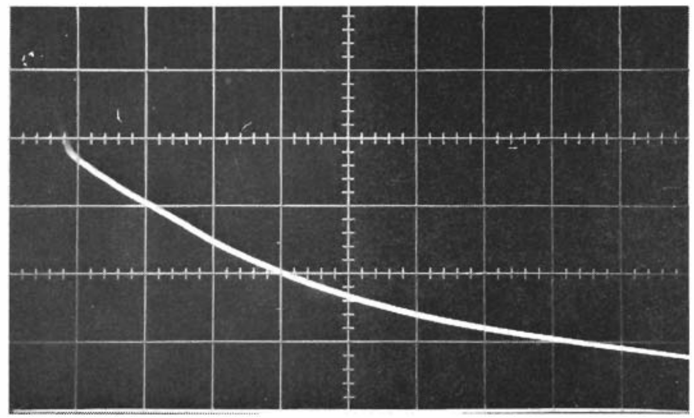
The effect of shear on the density profile near Ψ_c is shown in Figure 9. Ψ_c is at 1" from the wall. There is a plateau extending from approximately one gyroradius inside Ψ_c to one gyroradius from the wall. This is consistent with the idea of flutes driving plasma out in this region. When the B_θ field is added, this plateau is reduced and perpendicular electric field fluctuations which appeared outside Ψ_c are also reduced. The shearless point is at ~1 3/4" and there is a flat region in the density profile. This is also the region where field perturbations have a great effect on field topology and are seen to cause large potential spikes. These effects were discussed in the paper by J. Schmidt.

Θ = CONST. PLANE: FLUX PLOT

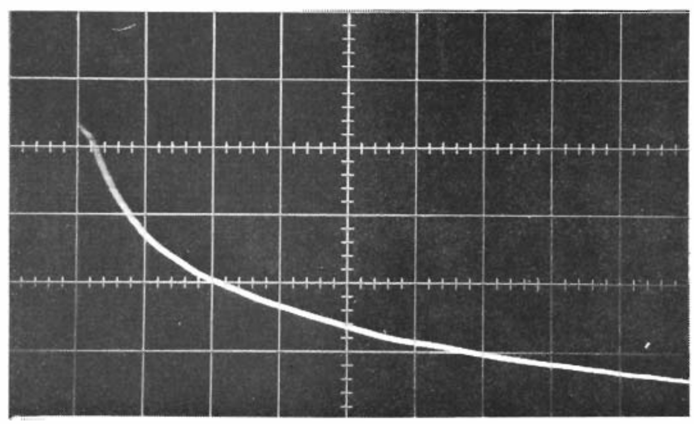


ION SATURATION CURRENT

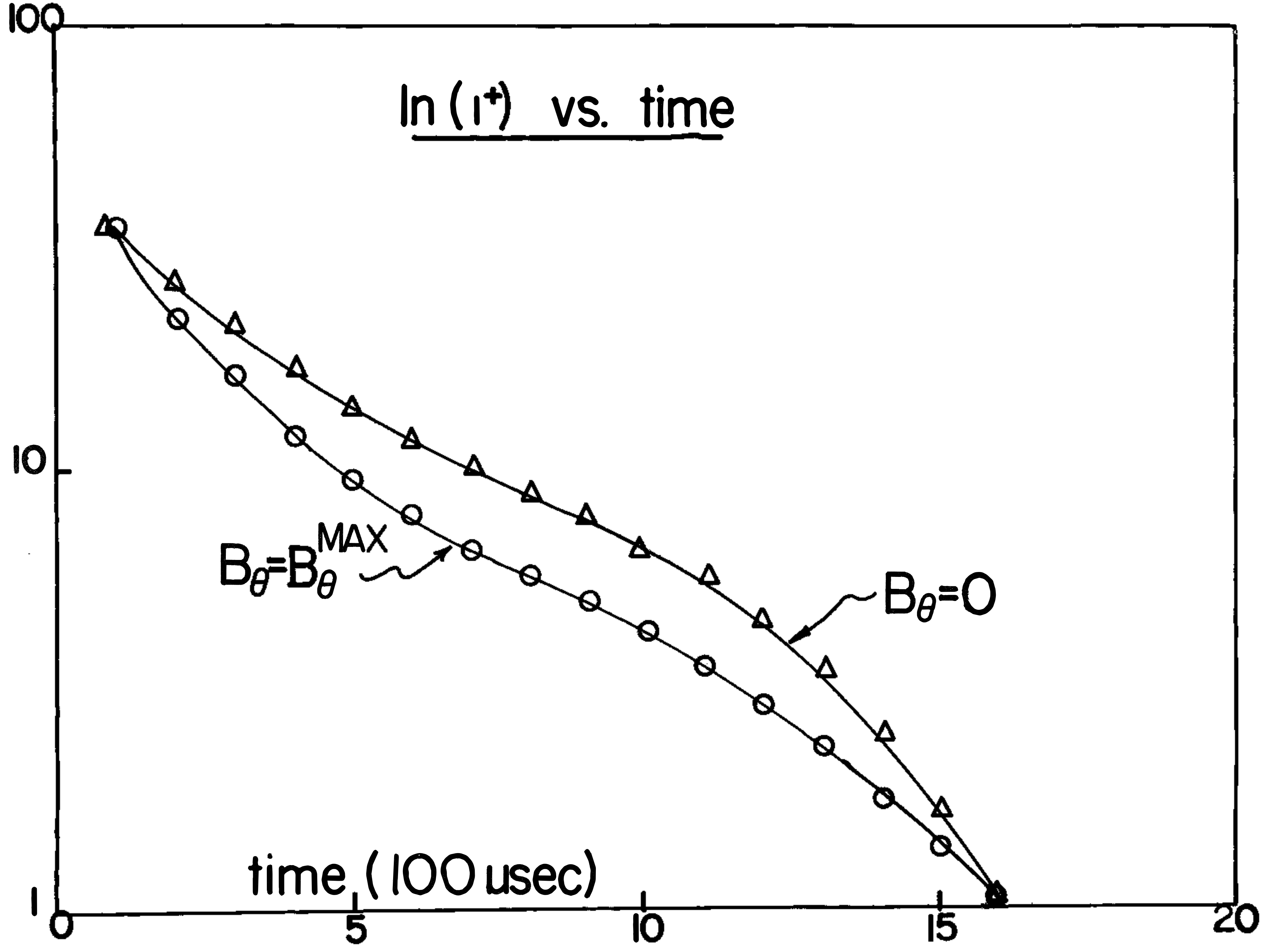
$B_\theta = 0$



$B_\theta = B_\theta^{Max.}$



1m sec



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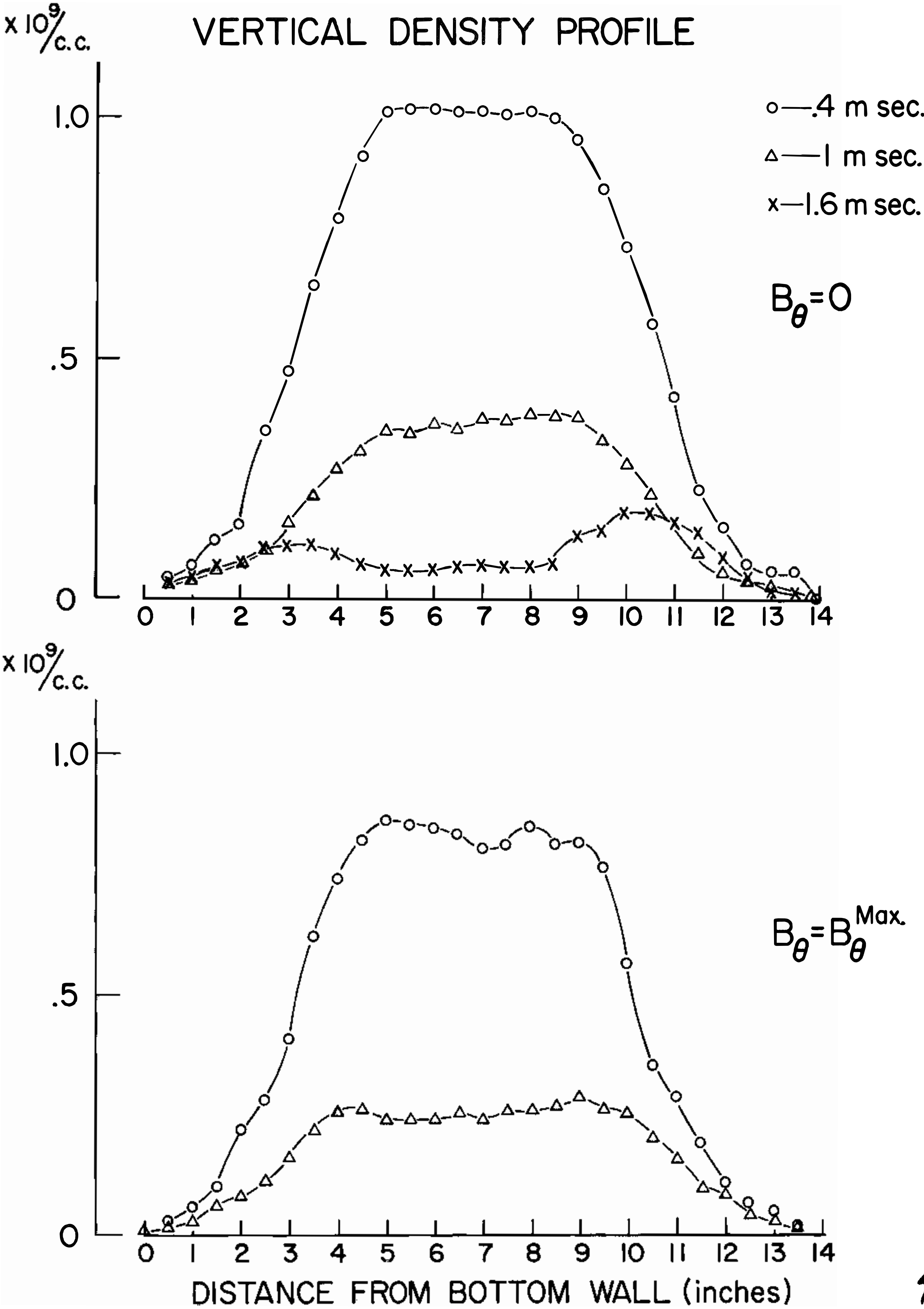
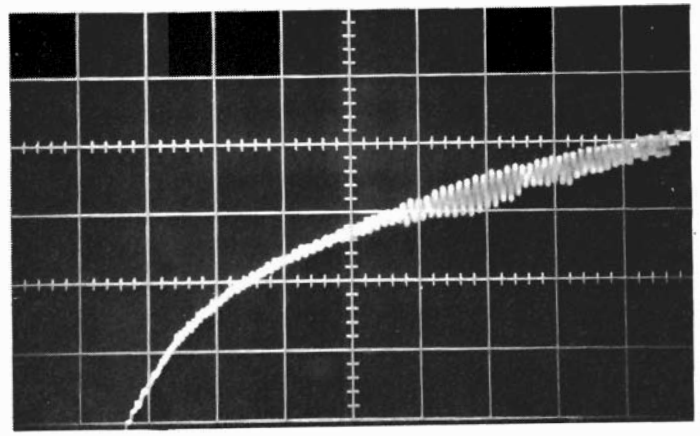


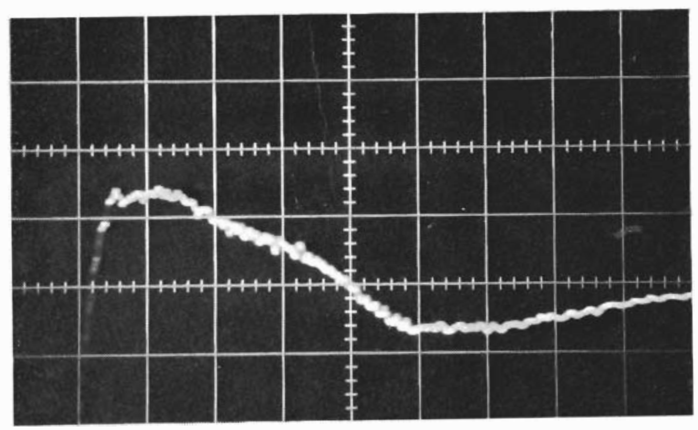
VERTICAL DENSITY PROFILE
x 10⁹/c.c.
1.0
.5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
○—.4 m sec.
△—1 m sec.
x—1.6 m sec.
$B_\theta = 0$
x 10⁹/c.c.
$B_\theta = B_\theta^{Max.}$
DISTANCE FROM BOTTOM WALL (inches)

FLOATING POTENTIAL (1 V/DIV.)
($r = 3''$, $\phi = 45°$)

$B_\theta = 0$



$B_\theta = B_\theta^{Max.}$



← 500 μ sec →

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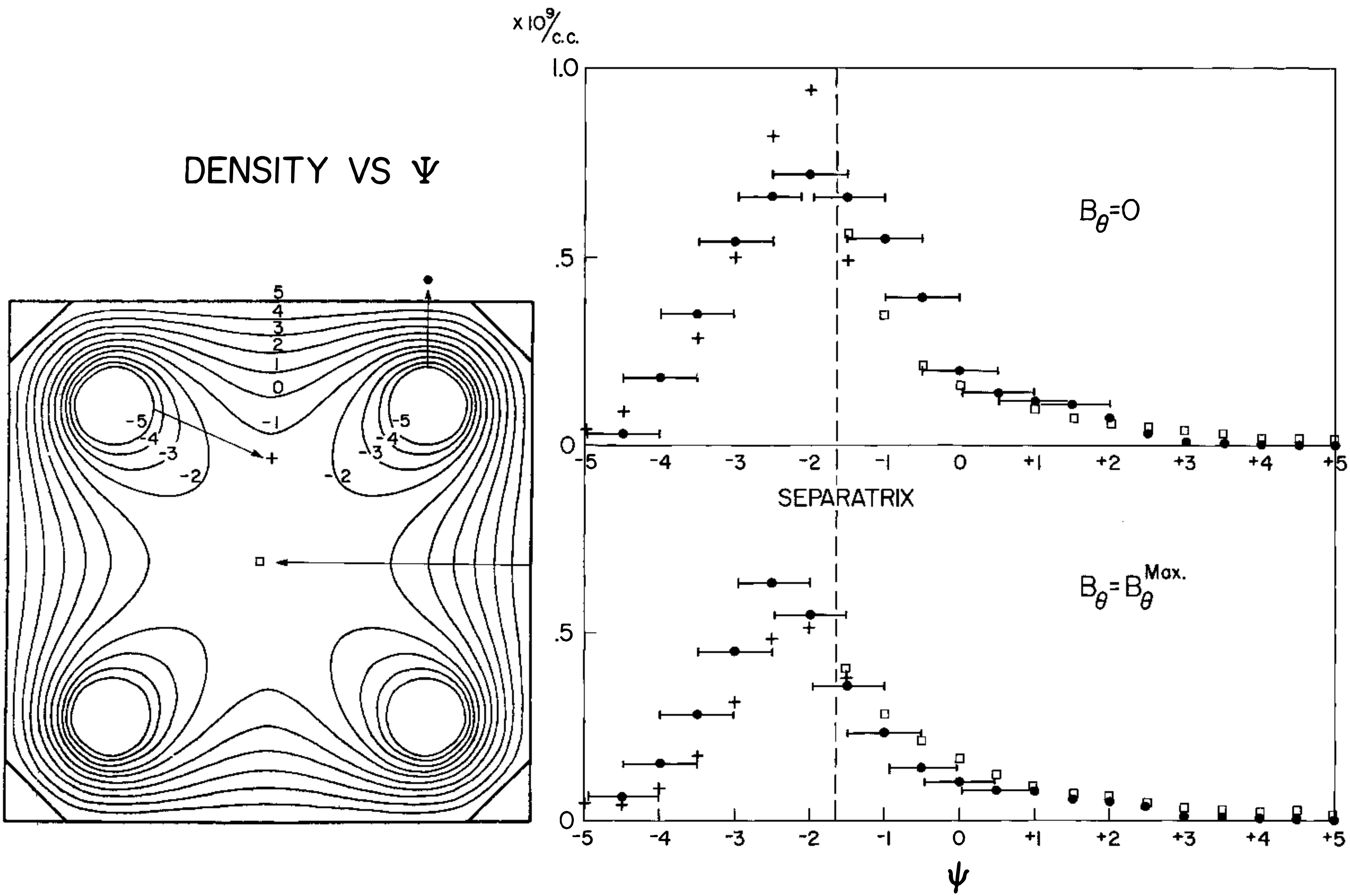
DENSITY VS Ψ



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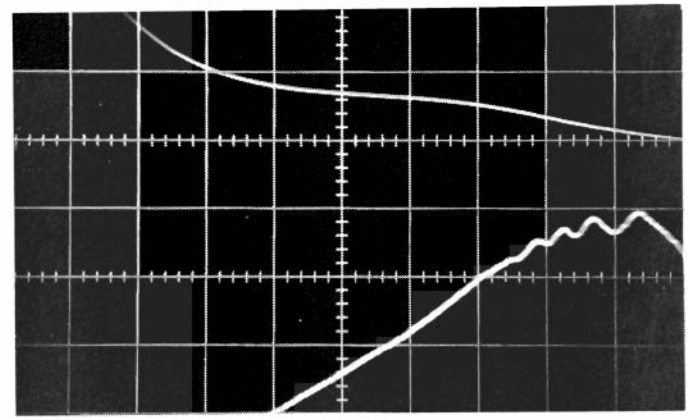
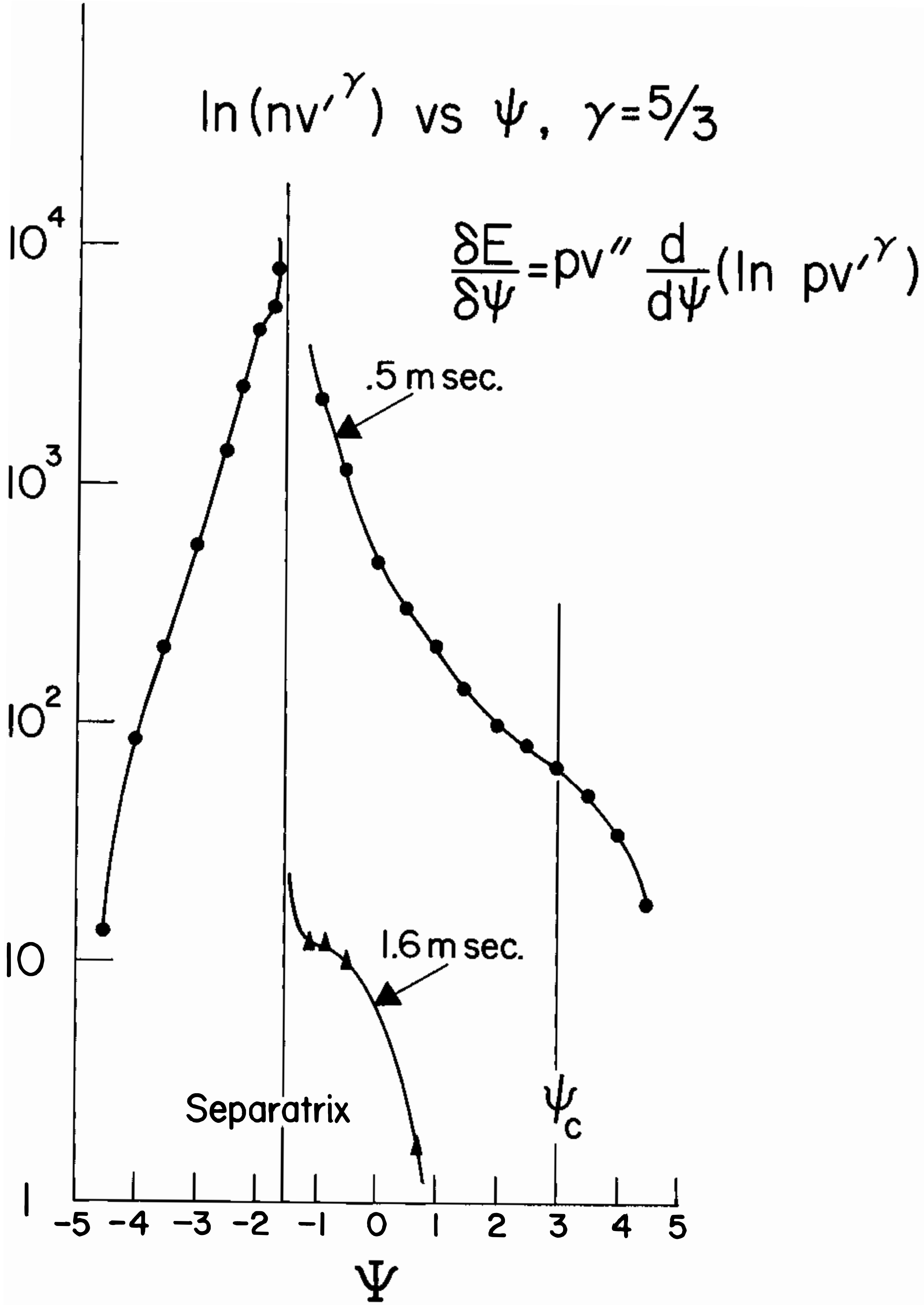
Ion Saturation Current

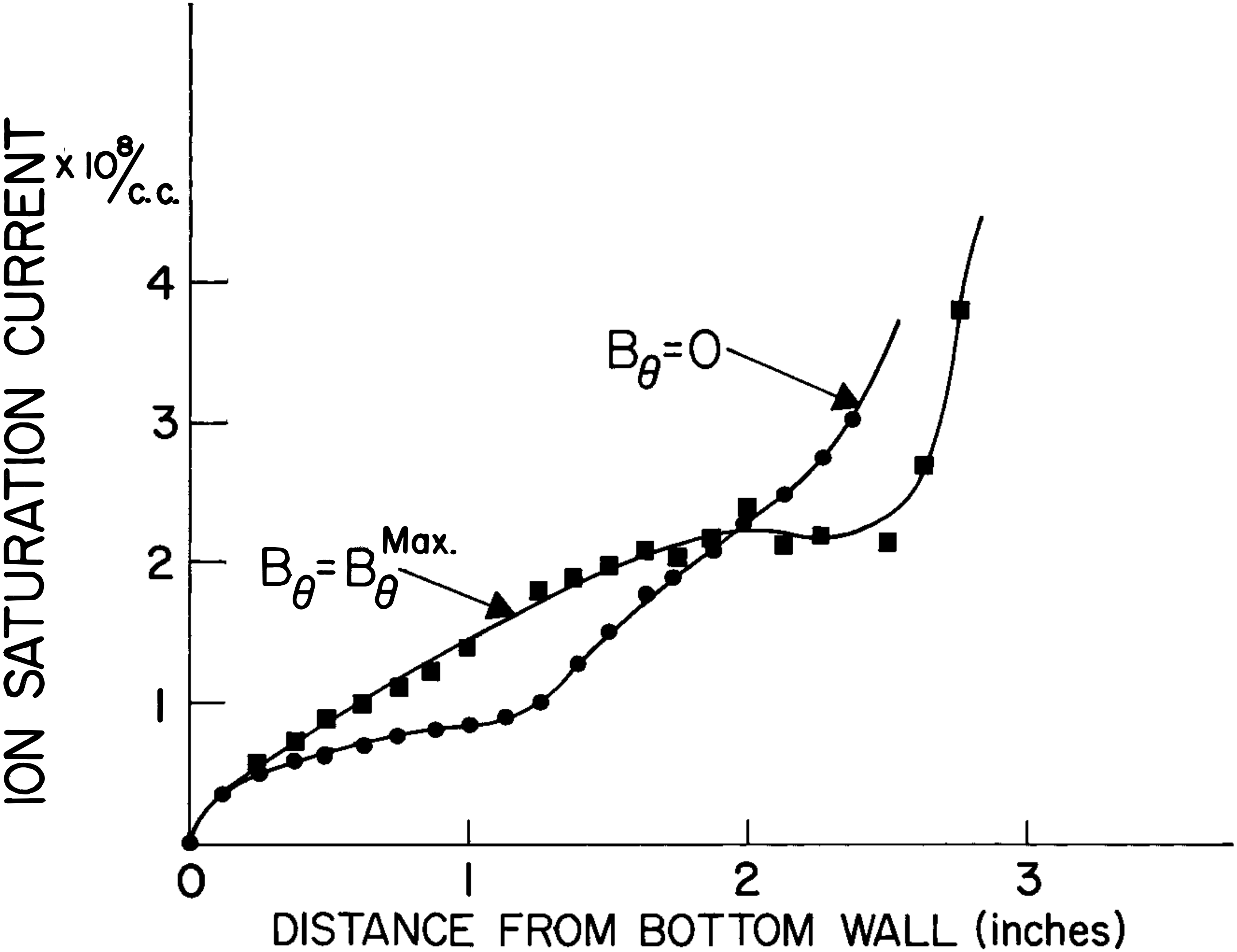
Floating Potential (.5 V/Div.)



(3 7/8" from bottom wall)



ln (nv′^γ) vs ψ, γ=5/3
δE/δψ = pv″ d/dψ (ln pv′^γ)
10⁴
10³
10²
10
1
.5 m sec.
1.6 m sec.
Separatrix
ψc
-5 -4 -3 -2 -1 0 1 2 3 4 5
Ψ


ION SATURATION CURRENT x 10^8/c.c.
4
3
2
1
0
1
2
3
DISTANCE FROM BOTTOM WALL (inches)
$B_\theta = 0$
$B_\theta = B_\theta^{Max.}$

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