Measurement of Radial Loss and Lifetime of Microwave Plasma in the Octupole

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The number of particles in the toroidal octupole was measured as a function of time by three independent measurements. These measurements were used to calculate the fraction of plasma lost to the walls, the lifetime of the plasma, and the approximate electron temperature.

A cold ion plasma was produced in the usual manner by a 150 μsec pulse of 3 GHz microwave power. The microwave pulse began 1100 μsec after the start of the 5000 μsec magnetic field pulse. The start of the microwave pulse is called $t = 0$. The magnetic field rose to a peak value of 370 gauss at the outside wall midplane at $t = 1000$ μsec and fell to zero at 4000 μsec. A plasma with density strongly peaked near the separatrix was thus produced.

The flux of particles to the hoops and hangers was measured by using two pairs of hoops as a floating double probe biased to 9 volts. At higher bias voltages, a discharge occurred, as evidenced by large bursts of particles to the hoops.

The flux of particles to the wall was measured by two methods, giving identical results. One method used a circular collecting baffle which extended from the bottom wall to ψ_{crit} (about 2.5 cm) and encircled the entire major axis of the toroid. The collector was biased negative with respect to the wall and used as a single probe. The other method, from which the data presented here was obtained, consisted of biasing the hoops +9 volts with respect to the wall and measuring ion saturation current to the wall.

The result of the two measurements is shown in Figure 1. It is apparent that the flux of particles to the wall is ∿ 2-3% of the total particle loss during the time that the field is rising and that the fraction is sharply decreasing. When the magnetic field starts to decrease (∿ 1000 μsec), the field lines move out toward the wall carrying a large amount of plasma to the wall. When the magnetic field is almost zero, a burst of particles strikes the hoops or hangers.

The small radial loss for the microwave plasma is in striking contrast to the radial loss of gun plasma which may amount to as much as 50% of the total loss, as indicated by identical measurements. The explanation of this difference may contain information crucial to the understanding of plasma confinement in toroidal multipoles.

The number of particles in the machine at time t can be determined by integrating the flux of particles to the hoops and hangers and wall from t to ∞ :

$$N(t) = \frac{1}{e}\int_t^{\infty}\left[2\, I_{oi}^{H}(t) + I_{oi}^{W}(t)\right] dt. \tag{1}$$

N(t) obtained in this way is plotted in Figure 2. Over a considerable range (500 - 2500 μsec), N(t) decreases exponentially with a lifetime of 3 msec.

The number of particles in the machine can also be determined by using a microwave cavity perturbation technique. 23.9 GHz radiation was used and the frequency shift of some high order modes was measured as a function of time as the plasma decayed. The number of particles N(t) present at time t is then given by

$$\frac{\Delta f(t)}{f} = \frac{\bar{n}(t)}{2n_o} = \frac{e^2}{2\pi f^2 mV} N(t) \tag{2}$$

where V is the volume of the cavity (3.0×10^5 cm^3).

N(t) obtained by this method is also shown in Figure 2. The values are about 50% higher than the particle loss measurements. This difference may indicate that some of the lost particles are not being collected, as, for example, if some of the ions strike the positively biased hangers when the hoops are used as a double probe. Over the range 500 - 2500 μsec, the lifetime is identical to that obtained from the particle loss measurements.

The third method of measuring N(t) consisted of using a single 1/8" x 1/8" cylindrical Langmuir probe biased to -45 volts to measure ion saturation current as a function of space and time. N(t) can then be found from

$$N(t) = \int_{-5}^{5} n(\psi,t)\ V'(\psi)d\psi \tag{3}$$

where $V'(\psi) = dV/d\psi$ and $n(\psi', t)$ is obtained from the ion saturation current by

$$I_{oi} = neA\sqrt{\frac{kT_e}{2\pi M}} \quad (4)$$

where A is the collecting area, T_e is the electron temperature and M is the ion mass.

Since there is considerable doubt about the reliability of the probe measurement of T_e, equation (3) was used to estimate T_e from the values of N(t) obtained by the other methods. A plot of ion saturation current vs ψ at various times is shown in Figure 3. Note that the plasma is initially peaked on the separatrix (500 μsec), moves in toward the hoops as the field increases (1000 μsec), and then moves out to the wall as the field decreases (3000 μsec).

The value of $T_e(t)$ obtained in this way is shown in Figure 4. This figure is not meant to be taken too seriously because it is only a crude estimate of T_e. For example, as the plasma decays, the sheath thickness changes and the effective collecting area of the probe changes. Furthermore, azimuthal density variations, which are known to be appreciable during the first 1000 μsec, have been ignored. The point of this calcualtion is to show, first, that the electron temperature is probably considerably less than the 10 eV read by probes, and, second, that the rate of temperature decay is probably quite fast in agreement with theoretical predictions based on ionization and excitation losses.

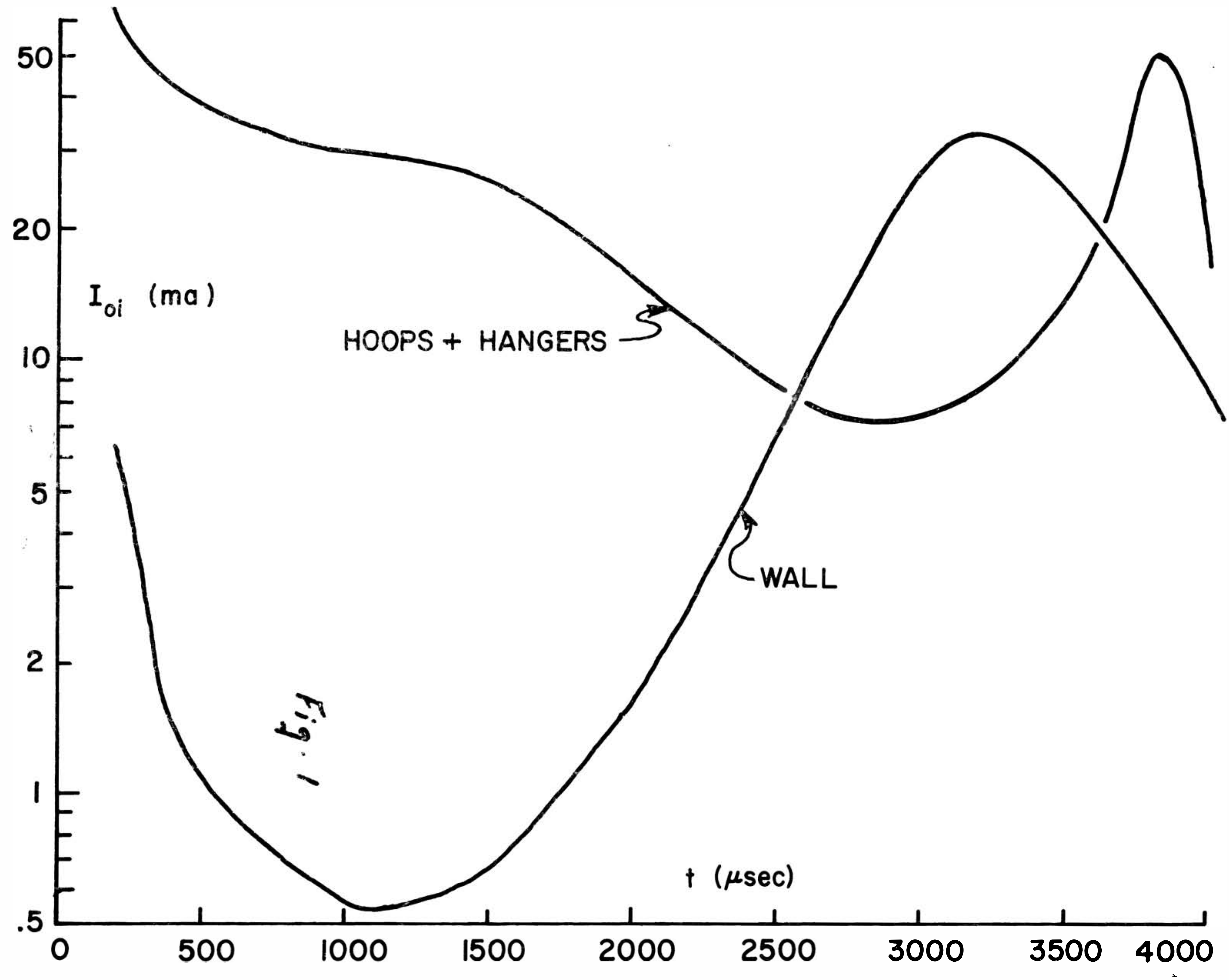
This preliminary work has raised a number of important questions which remain to be answered by future experiments:

1. Why is the radial loss of microwave plasma so much less than the gun plasma? By what mechanism are particles reaching to the wall in the two cases?

2. What fraction of the particle flux to the hoops and hangers is to the hoops? By how much would levitated hoops or successfully guarded hangers increase the lifetime? Why is the lifetime not significantly increased by present guarding techniques?

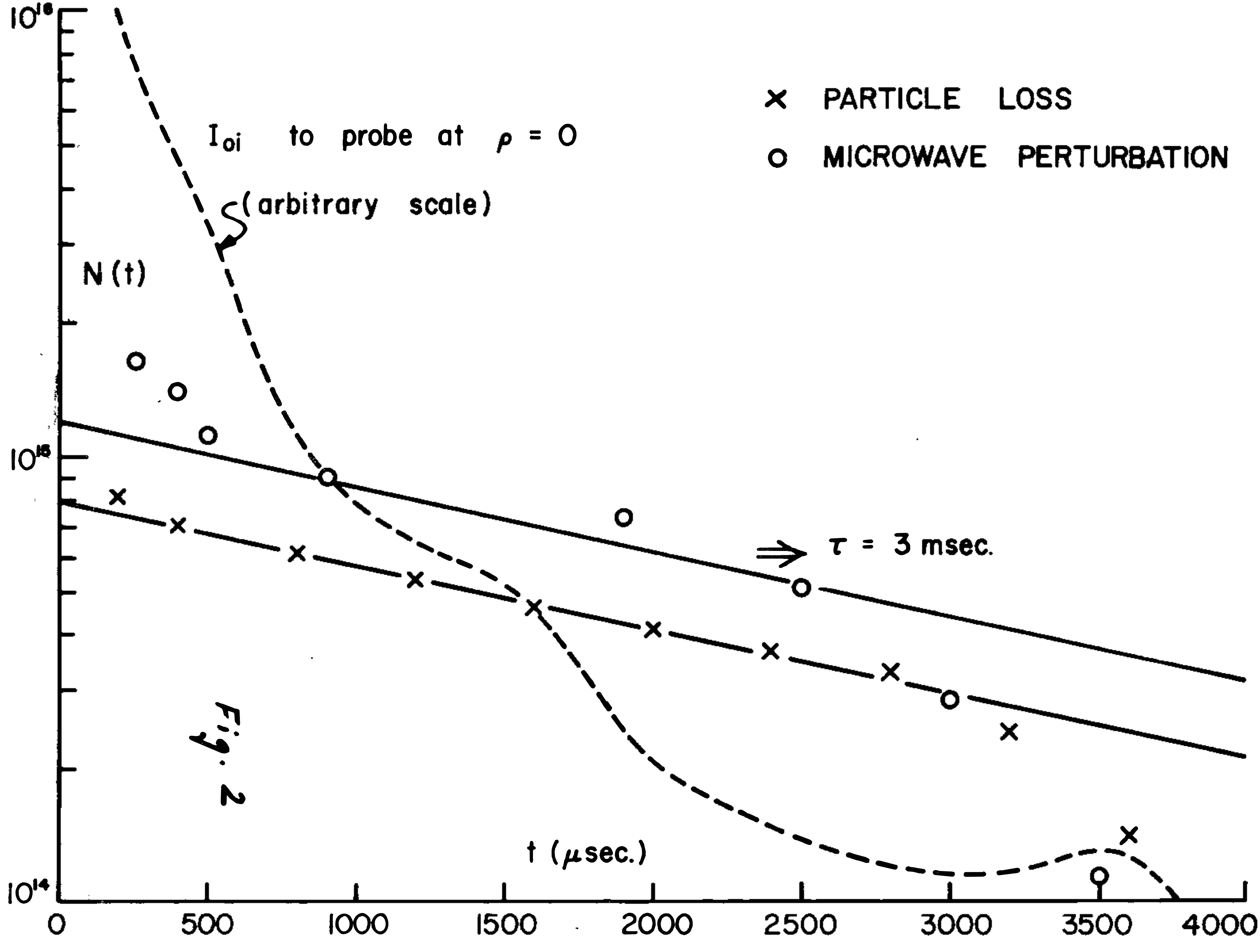
3. Why do probes not read the correct electron temperature? Does this error relate to the yet unresolved floating potential paradox? What is the true electron temperature?

4. To what extent can the differences in behavior of the microwave and gun plasma be attributed to high background gas pressure and low electron temperature, as opposed to merely a difference in ion temperature?



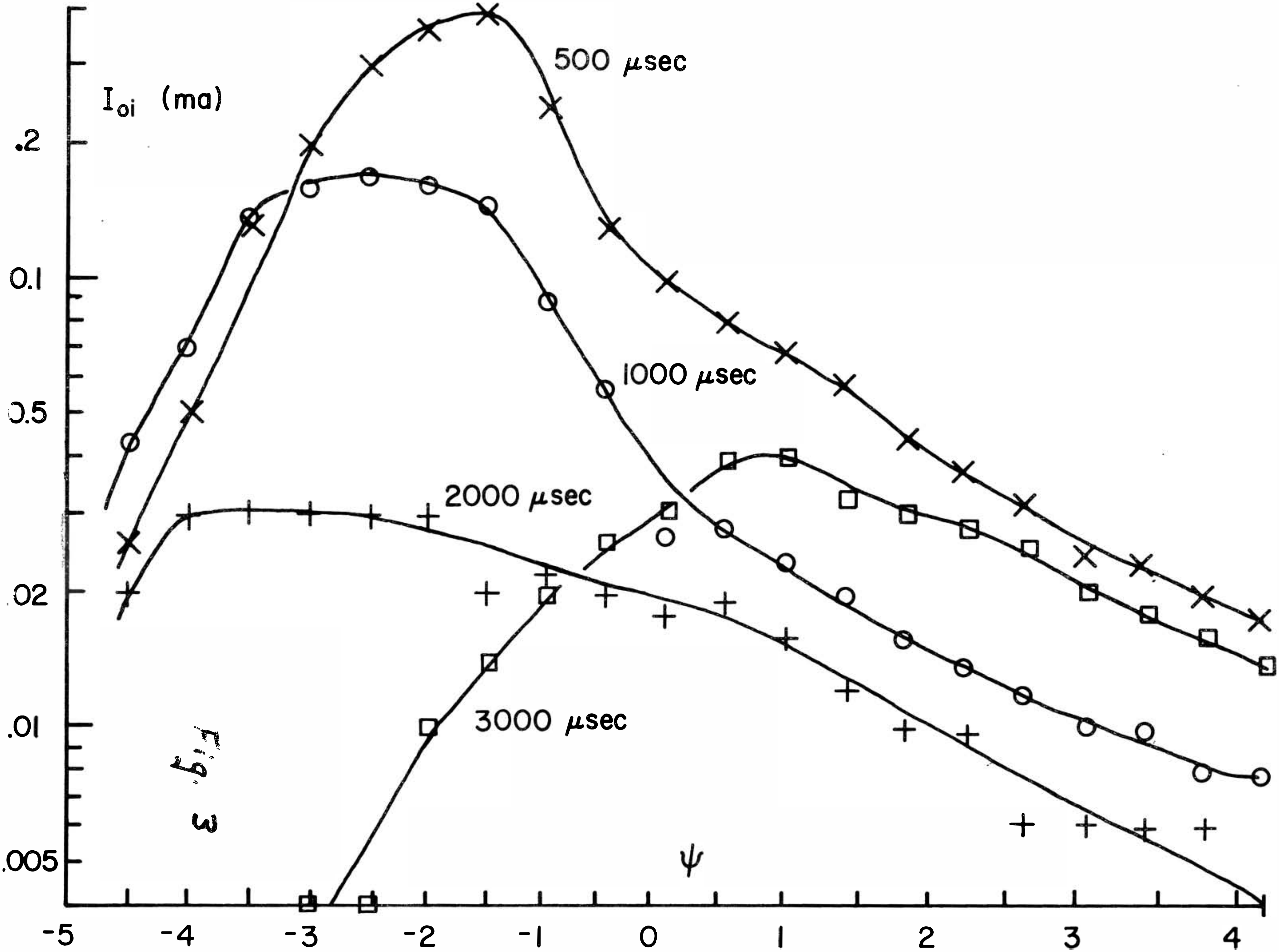
50
20
10
5
2
1
.5
I_{oi} (ma)
HOOPS + HANGERS
WALL
t (μsec)
0
500
1000
1500
2000
2500
3000
3500
4000

Fig. 1



10^{16}
10^{15}
10^{14}
N (t)
I_{oi} to probe at $\rho = 0$
(arbitrary scale)
× PARTICLE LOSS
○ MICROWAVE PERTURBATION
$\Rightarrow \tau = 3$ msec.
t (μsec.)
0
500
1000
1500
2000
2500
3000
3500
4000

Fig. 2



I_{oi} (ma)
.2
0.1
0.5
.02
.01
.005
500 μsec
1000 μsec
2000 μsec
3000 μsec
ψ
-5
-4
-3
-2
-1
0
1
2
3
4

Fig. 3

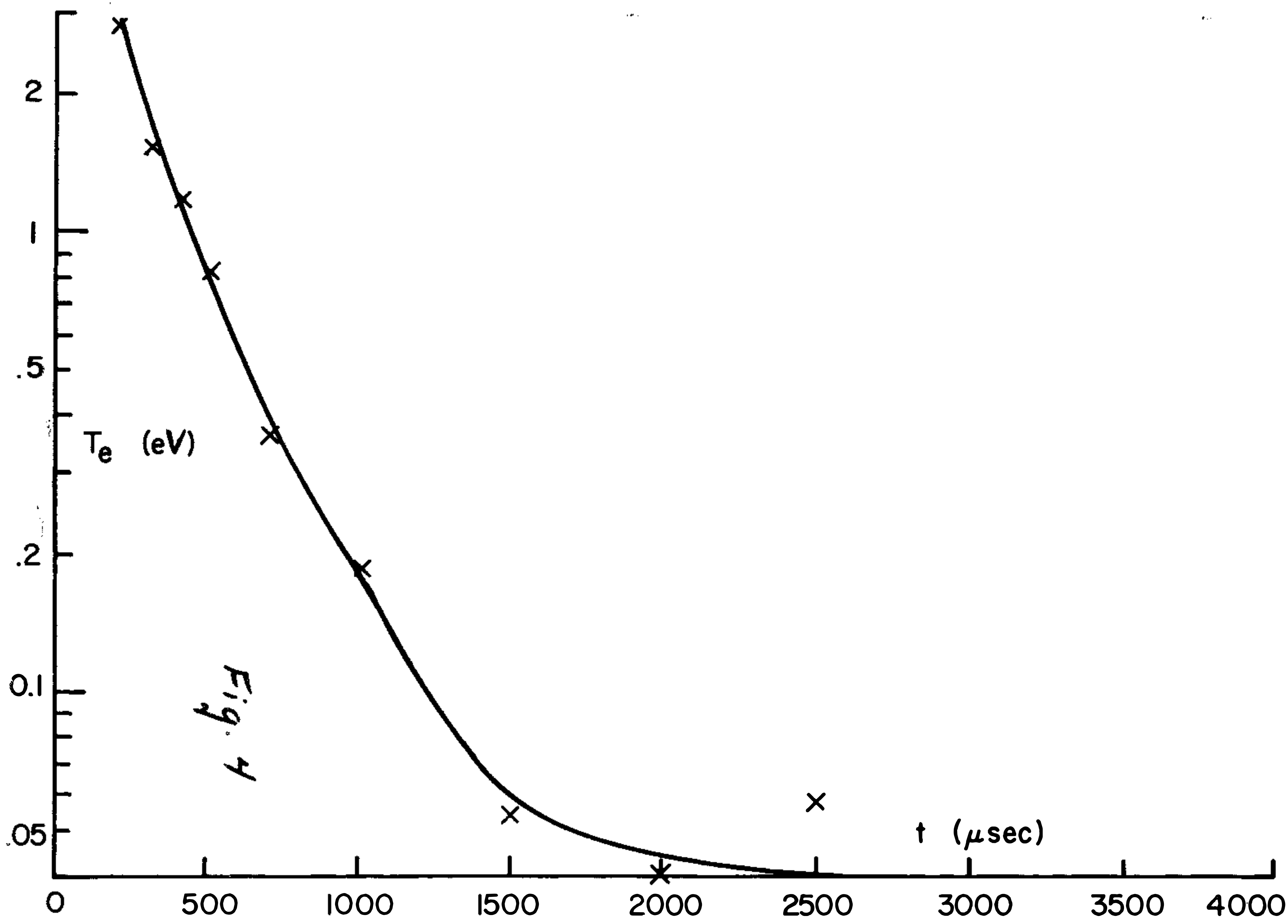


Fig. 4