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Neutral Impurity Emission During Operation of Intense Pulsed Ion and Electron Diodes

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Neutral Impurity Emission During Operation of Intense Pulsed Ion and Electron Diodes

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Abstract

The number of neutral particles (N) emitted during the pulsed operation of two magnetically insulated ion diodes and a typical electron diode were measured with an ionization technique. Among the factors which affect the total number of emitted neutrals were the elapsed time between consecutive firings and the power in the voltage pulse. A typical value of N for the electron diode (operating at $\approx$300 kV, 80 kA peak power) was 10^{19}, while values of N for the ion diodes (90–320 kV) were 3 to 30 times greater.

[illegible]

[illegible] power

Introduction

The number of neutral impurity particles (N) emitted during the production of intense charged particle beams is of interest for applications in magnetically confined fusion research and determining pumping requirements for multipulse operation. We have monitored the number of neutral atoms produced during the pulsing of two magnetically insulated ion diodes and a typical parallel plate electron diode.

Equipment and Measurements

The density of neutral particles was determined using a bare Schulz-Phelps ionization gauge (Westinghouse WL-22923). The ratio of ion current I_i to electron current I_e in the gauge during shots was compared to a calibration curve of I_i/I_e vs. known densities of air to determine the density in the vacuum chamber as a function of time following shots. A mass spectrometer was unavailable to us, thus the neutral gas composition was unknown. Because the calibration of the gauge was done for air, our values for N could conceivably be off by a factor of 3 or 4, however reasonable assumptions as to the gas composition can be made. Among the most probable gases emitted or produced during a shot (N_2, O_2, H_2, CO, CO_2, hydrocarbons), only the hydrocarbons which can be produced from diffusion pump oil, and H_2, which is also derivable from pump oil, have gauge factors significantly different from 1 (gauge factors; $H_2 = 2.0$, CH's $\approx$ 0.2 to 0.4). If neutral emission from pump oil was significant there should be a tendency for the H_2 and CH's emitted to cancel each other somewhat in determining the total gauge factor for the unknown gas mixture. It should be noted that the relative values of N for shots taken under different conditions should not depend on the gauge factor assuming the ratio of the different gases emitted during a shot is the same for all shots.

Care had to be taken to insure that plasma, which is readily produced during shots, was not incident on the gauge as this initiated a discharge across the collector plates. Shielding was accomplished with aluminum foil baffles which prevented any plasma from having a direct line of sight to the gauge.

The gauge gave density as a function of time following a shot. We observed that there was emission of neutrals (above the background outgassing rate) as late as 150 msec after some shots. Thus to determine N an integration of density over time with an appropriate correction for pumping was necessary. We used a computer program which would, for time steps of 5 msec, first use the average density in the interval to calculate the number of neutrals removed by the pumping system (using a pumping speed of 150 ℓ/s which was empirically observed), and second, would use the empirical change in density to determine the change in the number of particles in the chamber. Adding the two terms gave a source term for that interval. Adding together all the source terms for each interval gave N.

A. Parallel Plate Electron Diode

The observations with the electron diode were performed using the CASTOR generator,[1] a 3 ohm water dielectric pulse-forming line driven by a 12 stage, 10 kJ Marx generator. The generator was operated with a 50 nsec pulse in the output range of 180-380 kV.

The diode consisted of two graphite plates, with an effective area of 112 cm^2. Their separation was varied from 0.35 to 0.65 cm to change the impedance. See Fig. 1(a) for typical diode voltage and current traces during a pulsing of the electron diode.

Two different vacuum chamber configurations were used, the first with a volume of 55 ℓ and the second with 27 ℓ. Aluminum was the primary construction material. It became apparent from the data that the characteristics of the chamber walls and their proximity to the diode were significant. Apparently some form of desorption of surface gas layers was occurring. The smaller vacuum configuration had a smaller amount of inner surface area but a large amount of that area was very close to the electron diode. The number of neutrals released during a shot with the smaller chamber was 10 to 60% greater than a similar shot with the larger chamber. The possibility that surface cleaning was occurring was also supported by the observation that N would decrease for consecutive shots, if those shots were taken with little elapsed time in between. At one point in the experiment 6 shots with the electron diode were taken consecutively with an elapsed time of one minute in between (using the 55 ℓ volume and with diode voltage 250 kV). At a later time three consecutive shots were taken with the 27 ℓ volume and a diode voltage of 320 kV. See Fig. 2 for the dependence of N on shot number for the two cases. Clearly N decreases with each shot in the series, and apparently N decreases faster with the higher diode voltage and smaller vacuum chamber. It was regularly observed that for consecutive shots separated by an hour or longer that N would not decrease from the first shot to the second.

Also investigated was the dependence of N on the voltage applied to the diode, with all of the other parameters held constant. Diode current and impedance are functions of time. The diode impedance at peak power was 3.5 ± 0.4 ohms for all diode voltages in the range 180-380 kV for a plate separation of 0.42 cm. See Fig. 3 for N vs. diode voltage for the 27 ℓ vacuum chamber.

B. Ion Diode No. 1

A magnetically insulated ion diode was added in parallel with the electron diode on CASTOR. The ion diode consisted of a solid cylindrical anode with a surrounding cathode. See Fig. 4 for a diagram.

A large current (5-25 kA) is pulsed through the cathode to create the insulating magnetic field. As with many ion diodes, the anode surface across from the cathode is grooved and filled with epoxy to serve as an ion source. The 55 ℓ chamber was used for this part of the experiment. The ion diode impedance was fixed at about 8.5 ohms (peak power), thus the spacing between the plates of the electron diode was changed to match the total load to the line (3.3 Ω). For more details on magnetically insulated diodes see elsewhere.[2] All the shots were taken with 320 kV across the diodes. After the system had pumped down to 5 x 10^{-5} T for two hours, five shots were taken consecutively (with several minutes in between). The system was then let up to atmosphere momentarily, and pumped down again. Another five shot series was taken. See Fig. 5 for N vs. shot number.

As was the case with the electron diode only, N decreases with each shot in a series. Letting the system up to atmosphere apparently replenishes surface contamination layers. The values of N obtained are about a factor of 3 or 4 higher than similar shots with the electron diode only.

All the neutral particles were not emitted during the first few milliseconds as we had originally anticipated. Figure 6 shows the empirical source function ($\frac{dN}{d\tau}$) as a function of time following two shots under similar circumstances. It can be seen that the source function varied considerably for shots of identical preparation, while N remained relatively constant.

C. "LONGSHOT" Magnetically Insulated Diode

Neutral emission data were also observed for another ion diode driven by the LONGSHOT generator, described elsewhere.[3],[4] A main feature of the LONGSHOT generator is its long voltage pulses on the diode (500-600 nsec for this experiment). See Fig. 1(b) for typical diode voltage and current traces.

For this experiment the diode voltage was fixed at approximately 90 kV. What we did vary was the charging voltage on the four capacitors in the Marx generator, which is proportional to the energy delivered to the diode. See Fig. 7 for a graph of N vs. charging voltage on each of the Marx capacitors. The values of N obtained for LONGSHOT are about an order of magnitude greater than for the ion diode used on CASTOR.

Discussion

Two important questions are: 1) Which surfaces were outgassing after shots, and 2) How can the outgassing be decreased.

With the parallel plate electron diode, the fact that N was greater for the vacuum chamber configuration with more surface area close to the diode, along with the fact that N decreases for consecutive shots with little elapsed time in between, strongly supports the contention that neutrals were being released from the chamber walls in significant numbers. The fact that N does not decrease for consecutive shots which are separated in time by over an hour (with the system at 5 x 10^{-5} T), makes diffusion pump oil a likely source of much of the neutral emission.

With the two ion diodes, it is likely that the plastic or epoxy anode was the greatest source of neutrals. This hypothesis is supported by the observations on the CASTOR generator. Under similar conditions (same diode voltage and power) the combination of the ion diode and electron diode in parallel would produce about a factor of 4 greater number of neutrals than the electron diode alone. Sputtering of neutrals from chamber walls by the ions accelerated in the ion diode would not be significant enough to cause the difference in N for the two cases. Barring some other mechanism which we have overlooked or underestimated, this leaves the anodes as the most likely source of the added neutrals. Also, we can actually observe extensive damage on the plastic or epoxy anode, which is evidence that vaporization of the anode and releasing of absorbed gases and anode material is occurring.

References

1. The Castor system was designed by S. C. Glidden as part of a joint project between the Laboratory of Plasma Studies, Cornell University, and the Kernforschungszentrum, Karlsruhe, FRG.
2. S. Humphries, Jr., Nucl. Fusion 20, 1549 (1980).
3. J. B. Greenly, Cornell University Laboratory of Plasma Studies Report 286 (1980).
4. J. B. Greenly, Cornell University Laboratory of Plasma Studies Report 315 (1983).

Figure Captions

Fig. 1 Voltage and current traces for (a) the electron diode on Castor (voltage - solid line, current - dotted line). The voltage trace is the same when an ion diode is added in parallel. (b) The magnetically insulated ion diode on LONGSHOT.

Fig. 2 N vs. shot number for a series of consecutive shots with the electron diode (X - 320 kV, O - 250 kV).

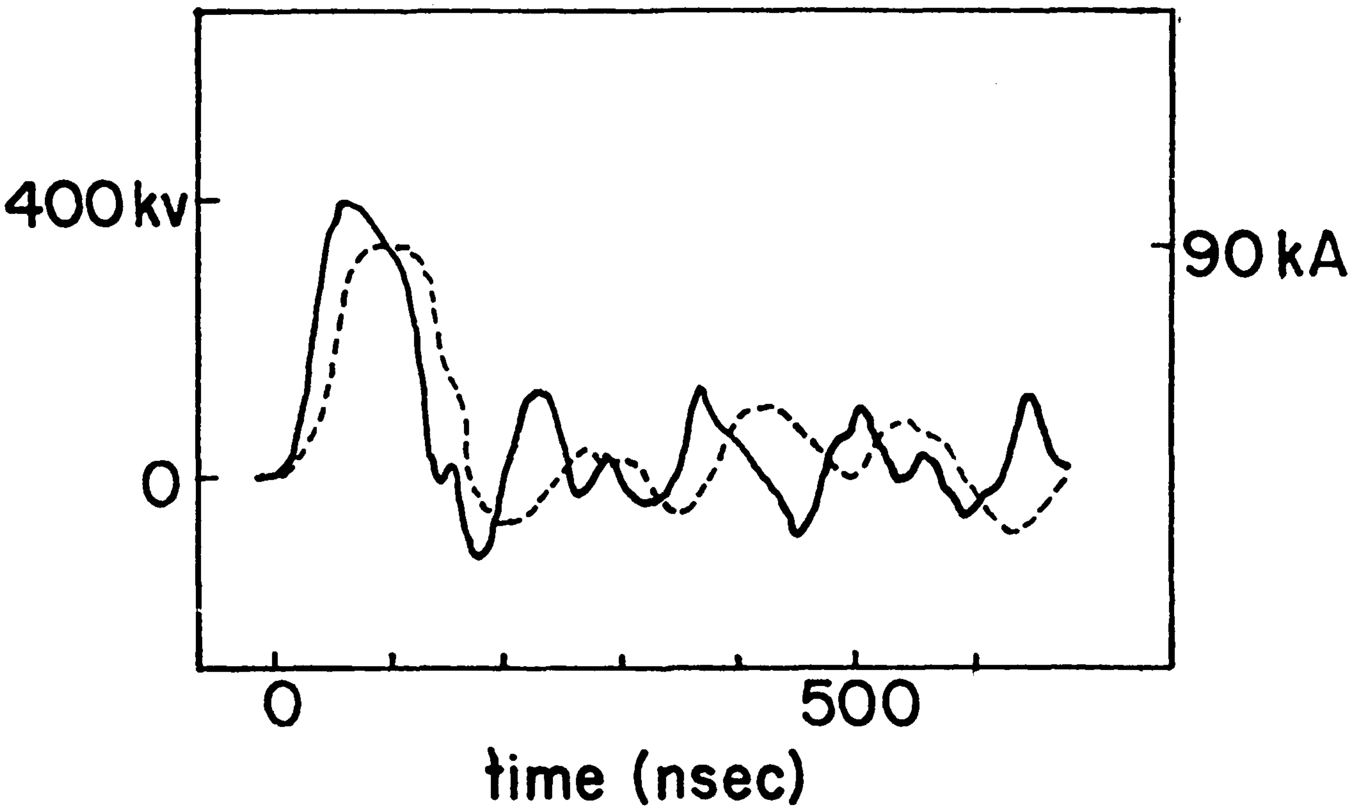
Fig. 3 N vs. diode voltage for the electron diode.

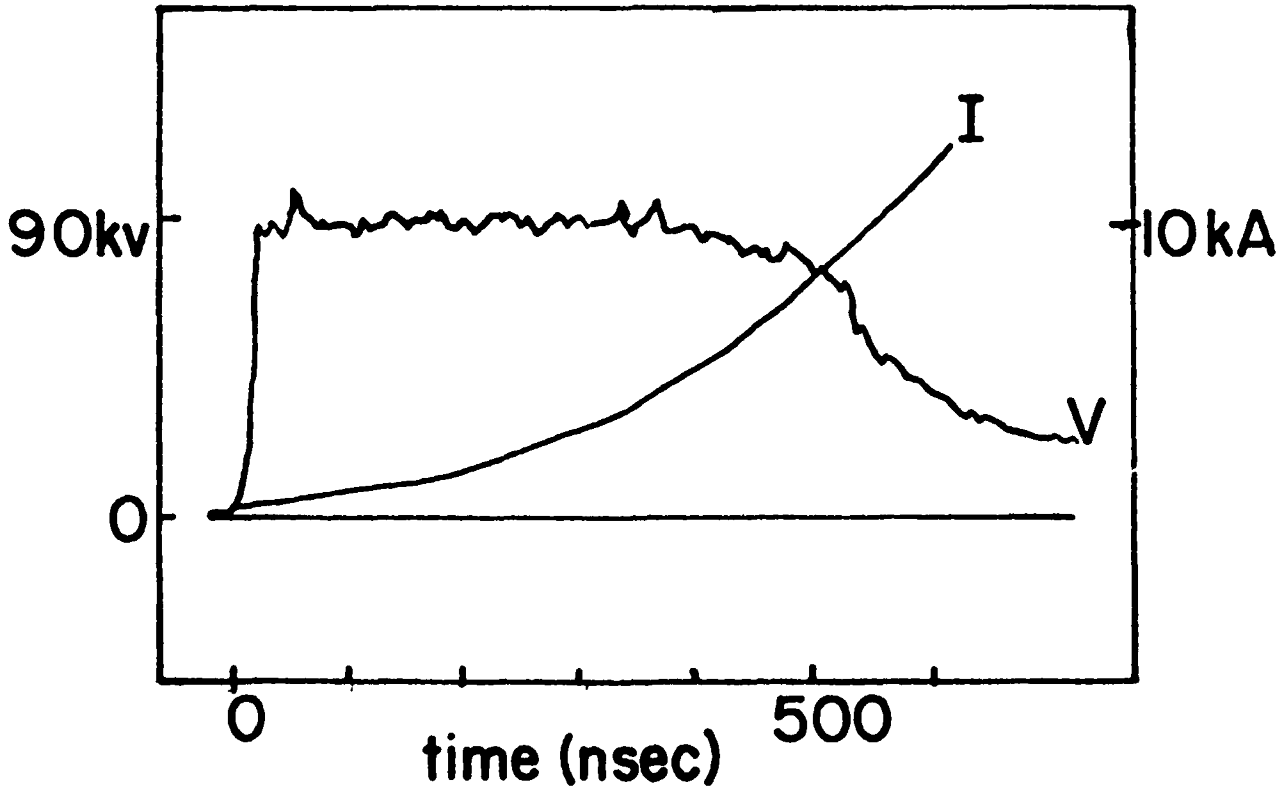
Fig. 4 Castor magnetically insulated ion diode.

Fig. 5 N vs. shot number for two series of consecutive shots with the Castor ion diode (320 kV).

Fig. 6 The neutral source function ($\frac{dN}{dt}$) as a function of time following shots #1, and #6 of the series of shots in Fig. 7. (A correction for the pumping speed of 150 ℓ/s has been made).

Fig. 7 N vs. charging voltage of Marx capacitors for LONGSHOT ion diode.





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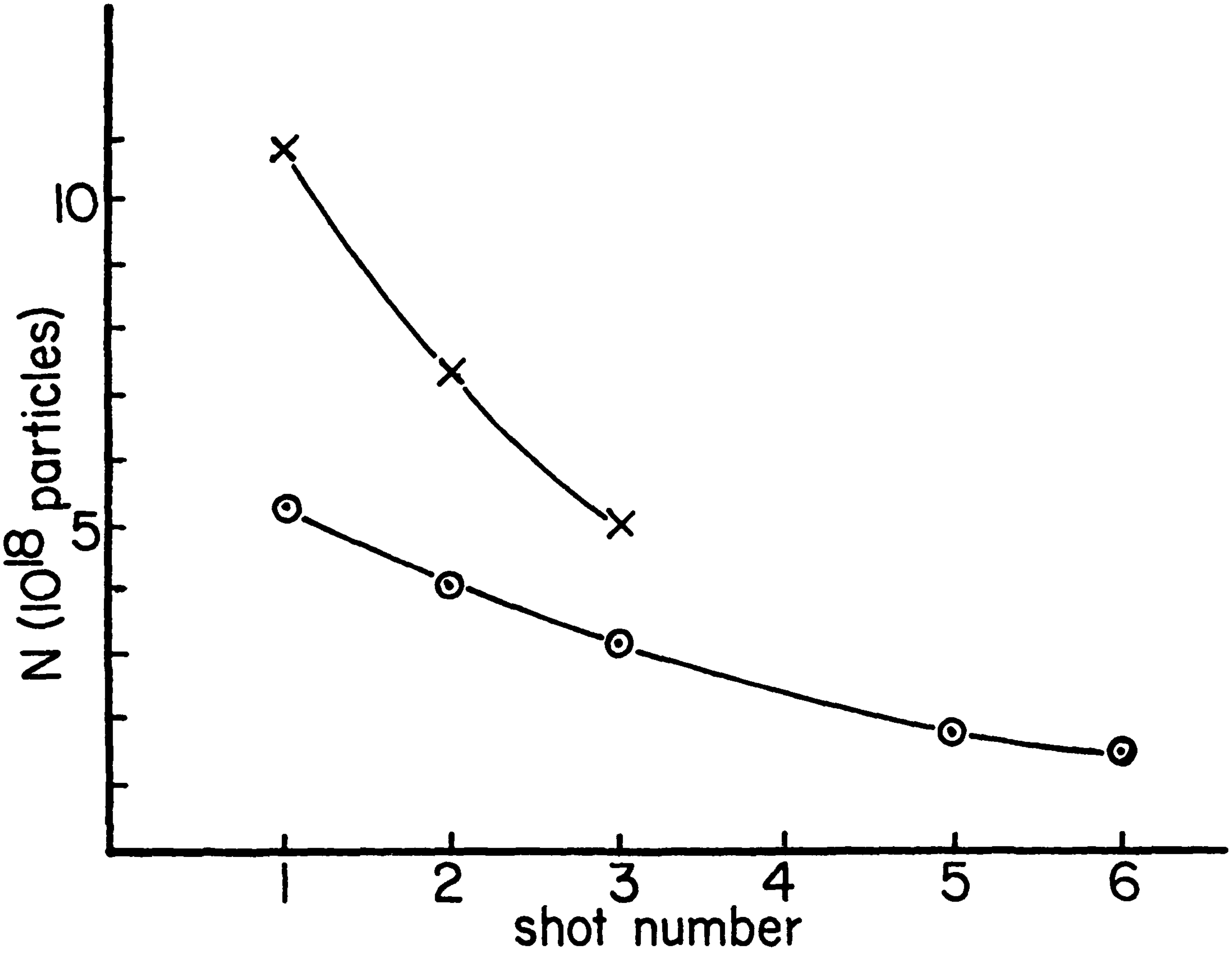

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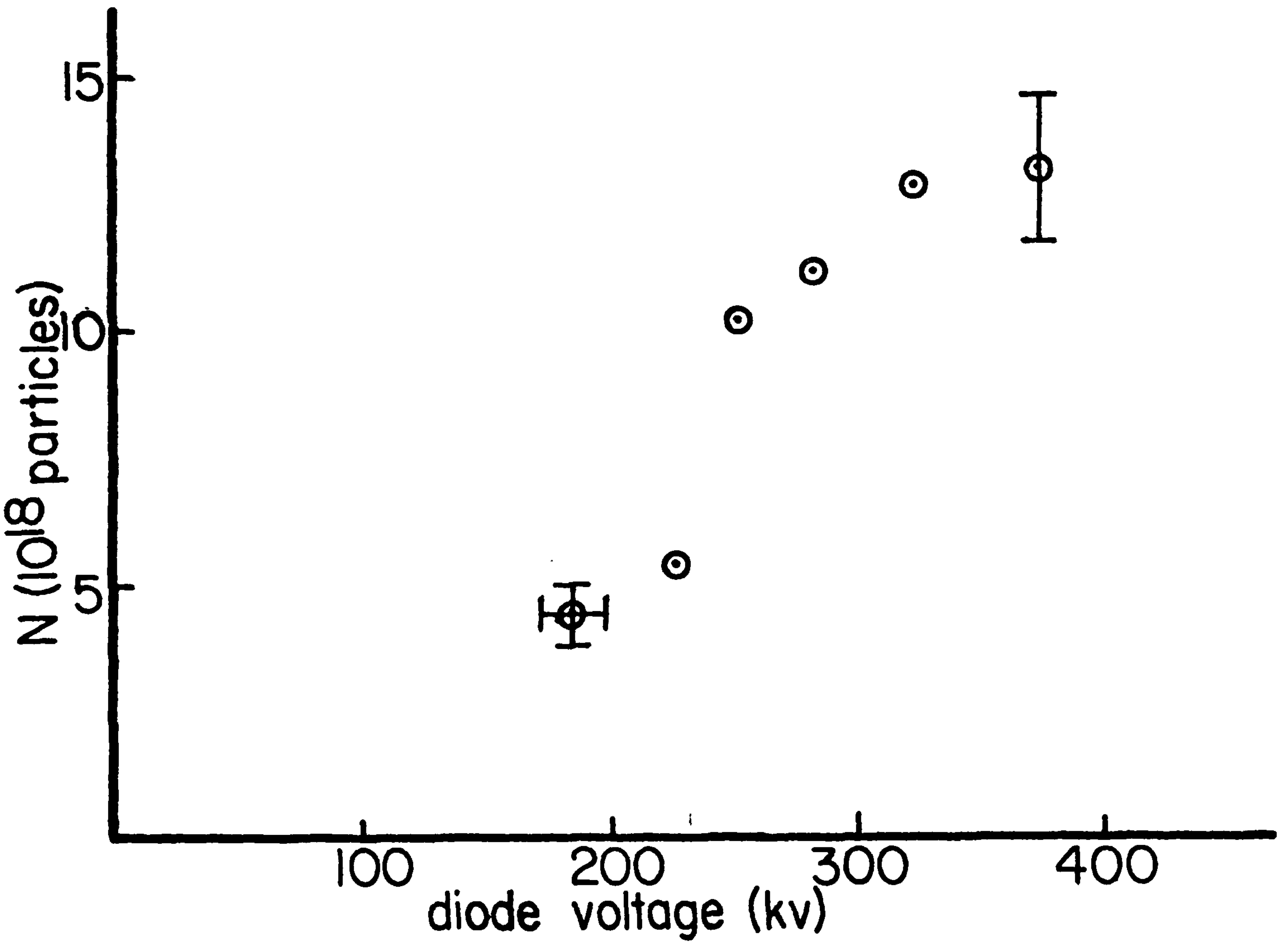

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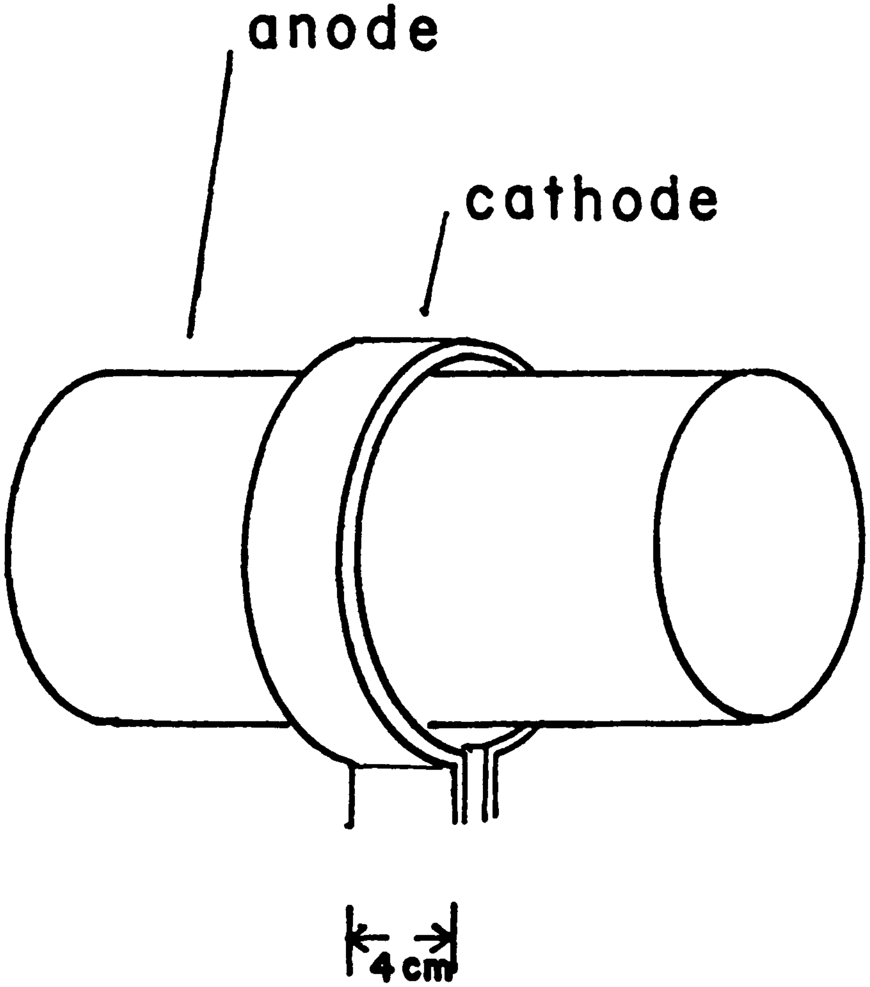

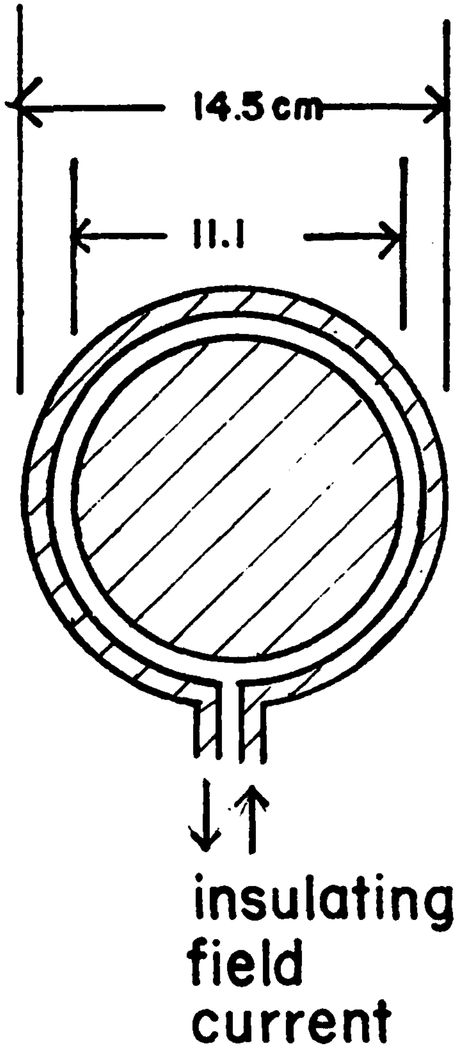

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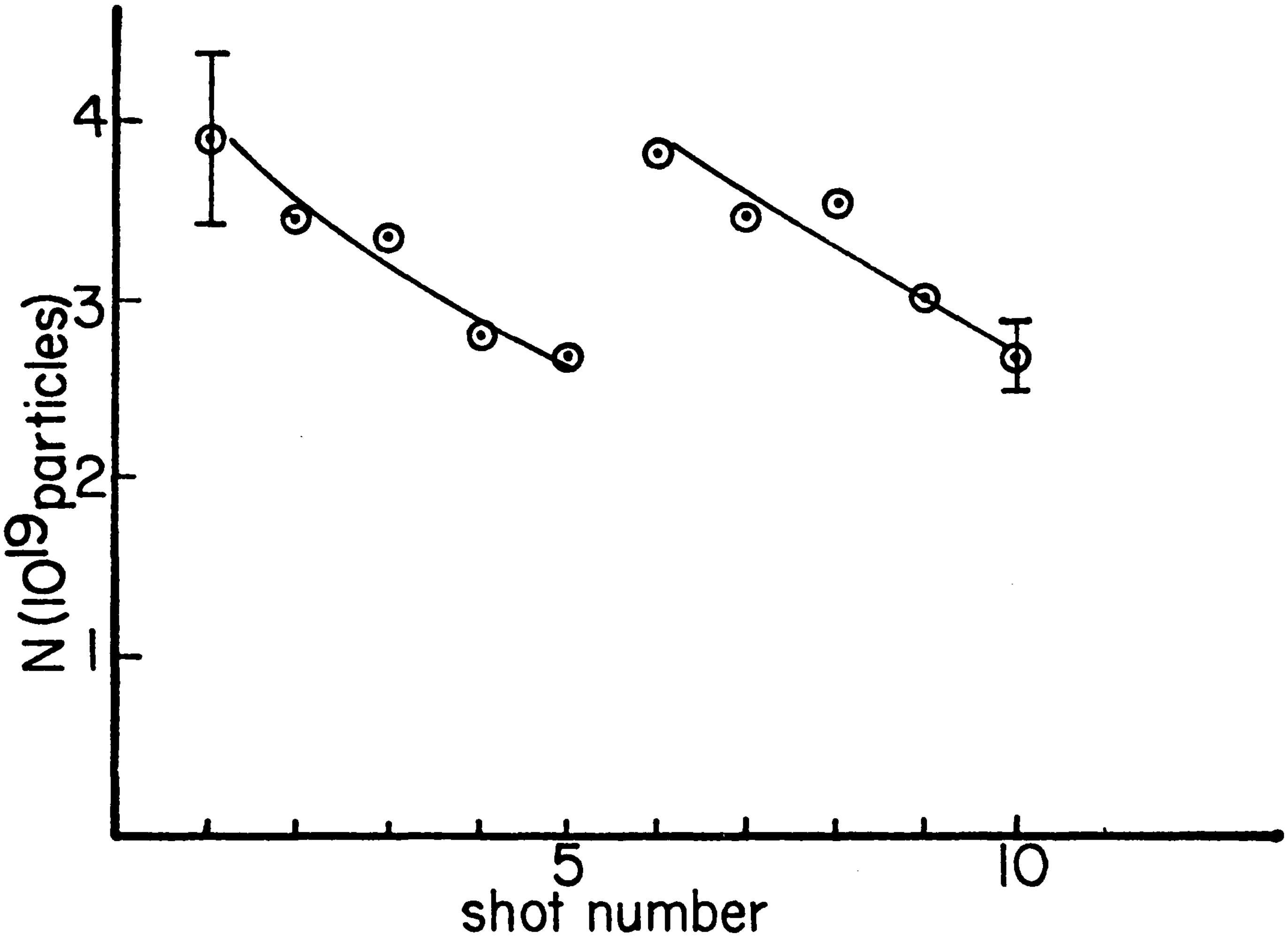

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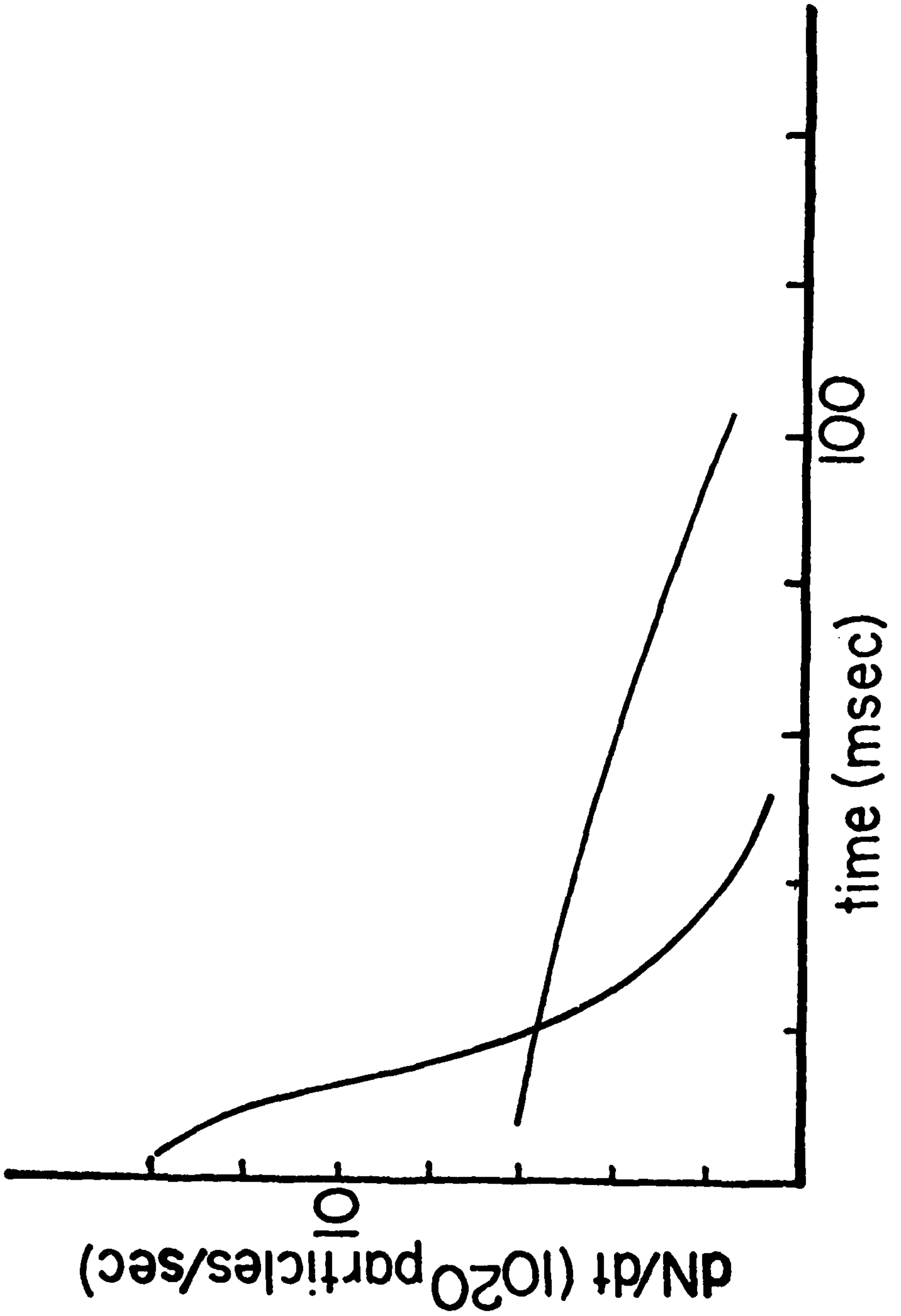
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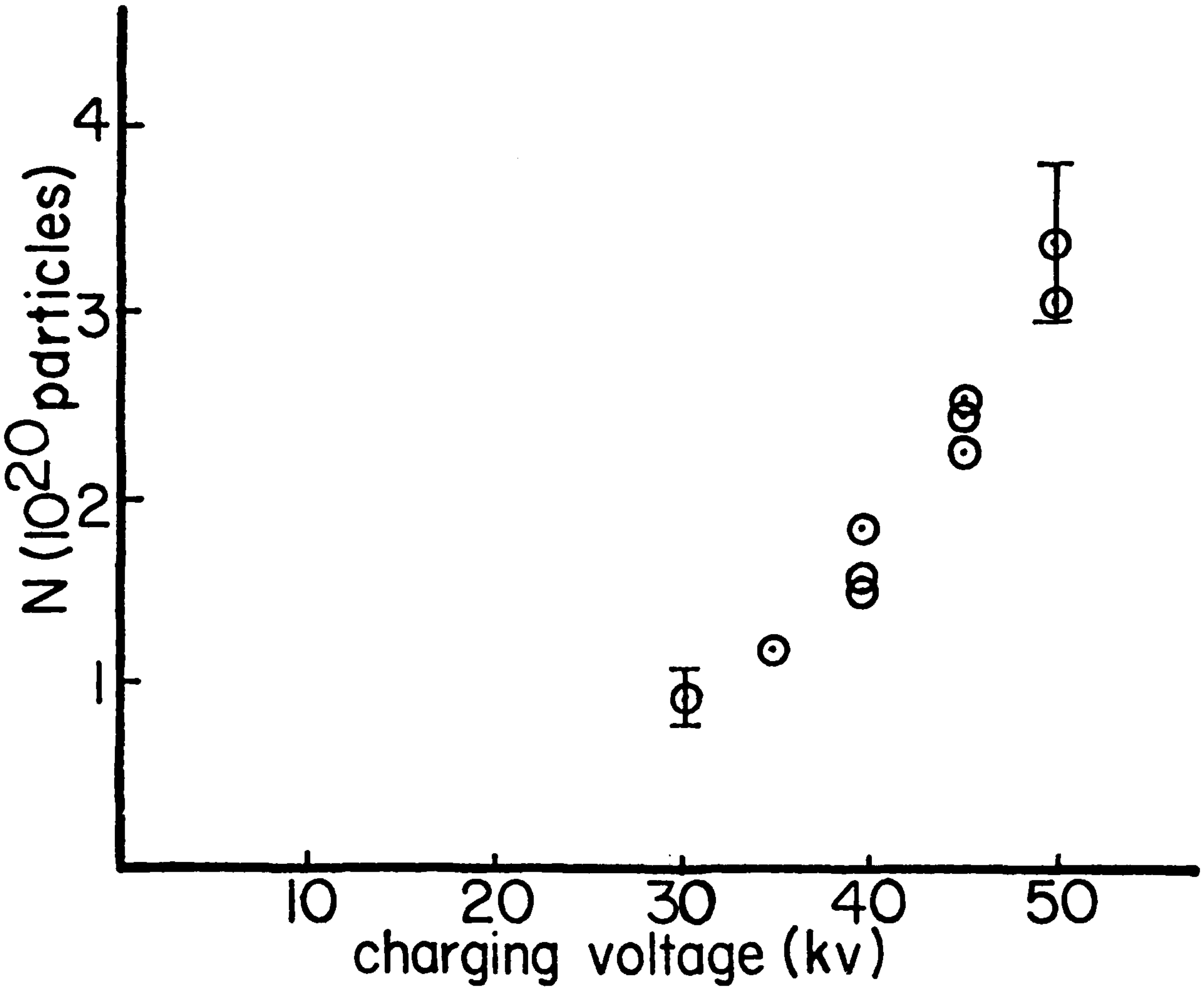
10
time (msec)
100


N (10^{20} particles)
4
3
2
1
10
20
30
40
50
charging voltage (kv)