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PARALLEL-PLATE PROPORTIONAL COUNTERS FOR RELATIVISTIC PARTICLES*)

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During the development of the multiwire proportional chambers (MWPC) we have investigated the possible applications, to other fields, of our findings on the properties of a remarkable gas mixture. This mixture permits a high gaseous amplification, above 10^8, without giving rise to the spread of streamers. A single photoelectron gives rise to an avalanche saturated by space charge effects with no further extension initiated by photons. The magic gas consists of the mixture argon + isobutane + CF_3Br + methylal. We have found that a mixture of argon + ethyl bromide + methylal has properties close to those of the first mixture. It permits operation at a lower voltage. However, two factors contribute to our preference for the first magic gas:

i) ethyl bromide is a dangerous gas and requires more safety precautions than do the components of the first mixture;

ii) the pulses have a wider pulse-height distribution than with the first mixture.

Since the magic mixture has such a strong quenching effect on the propagation of photons, we tried it in parallel-plate counters. Such counters have been operated since a long time in the proportional mode and in the spark mode, and have been the forerunners of spark chambers.

In the spark mode, time resolutions as good as 0.1 nsec have been achieved by Zavoiskii et al.$^{1)}$.

The first trouble with parallel-plate spark counters is their inherently large dead-time, similar to the one of a triggered spark chamber. Some progress in this field has been achieved by a recent development at Novosibirsk by Parchomtchouk et al.$^{2)}$. They cover an electrode with a semi-conductive glass (Fig. 1). This electrode is made of separated bands, and a spark is quenched by the resistive glass in series. The counter is only locally discharged, thus reducing the dead-time. A counter with 1 nsec resolution (FWHM) (Fig. 2) has thus been built, with a surface of 0.5 m^2.

If the time resolution could be brought down to the values reached by Zavoiskii, it would be a very good hodoscope, with a high time resolution and insensitive to magnetic fields. However, the large amount of matter introduced by the glass can be a nuisance. In the spark mode it is doubtful if dead-times comparable to those of photomultipliers or proportional counters could ever be reached.

In the proportional mode, Christiansen[3)] developed operational parallel-plate counters filled with vapours (methylal or ethyl alcohol) at low pressure. He finds that with a 1 cm gap, 4.2 cm Hg methylal, he has an operating plateau of about 100 V around 3000 V and that every ionizing event gives rise to a detectable pulse. He could run at rates close to a megacycle. However, because of the low pressure in the counter, only heavily ionizing particles give a 100% efficiency. Christiansen observes that the classical mixture of argon + organic quenching agent does not work, but only organic mixtures because of their high absorptive power for light quanta. This makes it natural to try out the magic gas with the aim of operating these chambers at atmospheric pressure.

PARALLEL-PLATE CHAMBER (PPC)

Several prototypes of parallel-plate chambers (PPC) with different geometry have been constructed and tested; all of them had only few cm^2 of active area.

A symmetric two-gap chamber gave the best results, and this for two reasons:

i) the outer electrodes, not being read out, could be well decoupled to ground thus reducing the pick-up problems;

ii) the pulse seen in the central electrode is the linear addition of the pulses produced by the gas amplification in the two independent gaps; this improves the pulse amplitude and the efficiency for minimum ionizing particles.

The prototype PPC with which the results to be described have been obtained, had a circular shape whose cross-section is represented in Fig. 3. The HV electrodes were made with a 0.2 mm thick brass sheet; the shape shown in the figure is to avoid edge effect. The active surface of the chamber was about 2 cm^2. The central electrode consisted of a thin 50 μ aluminium foil, the sensitive gap being 2 mm on each side.

To minimize the pick-up and noise problems as much as possible, two decoupling capacitors were connected between the cathodes and ground.

To detect the (negative) signals on the central electrode, an integrated fast amplifier with a gain of 100 *) with an input resistance R of 5 kΩ could be attached to the anode. The amplified signal was then handled by standard fast NIM electronics.

The experimental arrangement to study the efficiency of the chamber consisted of a ^{90}Sr collimated β-source, and two scintillation counters, placed behind the chamber; they gave the time reference and allowed only fast (minimum ionizing) electrons to be selected.

The "magic gas" (argon 23% + isobutane 0.4% + CF_3Br 4% + methylal) was the first gas filling we tried in the chamber, in view of its peculiar performances in a normal multiwire proportional chamber. It turned out, however, that although good pulses could be obtained from the PPC under these conditions, it was impossible to reach more than 80% efficiency on fast electrons. An explanation of this apparent contradiction can be the following. The electronegative properties of freon, well exploited in a normal MWPC where they allow a very high gain to be reached, in a PPC would limit the sensitive region around the anode to about 1 mm; this means that the primary electron produced at a larger distance will be captured before reaching the anode. Now, one can expect that in a PPC each primary electron will produce, by gas amplification, a charge proportional to 2^n, where n is the number of mean free paths for ionization between the initial position of the electron and the anode. If the mean distance between primary electrons is larger than the mean free path for ionization (as is the case for minimum ionizing particles) this means that most of the charge detected on the electrodes is produced by the longest avalanche. Restricting the sensitive region would then result in a reduced pulse amplitude for minimum ionizing particles; with the minimum threshold of detection, we were able to safely reach 300 μV on 5 kΩ. The gain was not sufficient to detect all particles with the magic gas.

Several other gas mixtures have then been tried, and the best results were obtained with a 60% argon + 30% isobutane + 10% methylal mixture, to which the following results refer.

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*) Fairchild μA733 Differential Wideband Amplifier.

TIME RESOLUTION AND EFFICIENCY

The pulse shape is easily predictable because of the simple geometry (see, for instance, Ref. 3). The electron pulse is

$$\Delta u_{el} = \frac{N_0 e}{c_z} \frac{1}{\alpha d} e^{\alpha d} ,$$

where

$\alpha = \alpha(E)$ is the first Townsend coefficient;

N_0 is the number of primary electrons liberated at the surface of the cathode or at the surface of the sensitive region;

d is the gap length;

c_z = capacity of the counter,

and the pulse induced by the motion of the heavy ions:

$$\Delta u_{ion} = \frac{N_0 e}{c_z} \left(e^{\alpha d} - \frac{1}{\alpha d} e^{\alpha d} \right) .$$

The electron pulse is αd times smaller than the one induced by the positive ions, corresponding to the fact that most of the electrons are liberated at a distance of a mean free path $1/\alpha$ from the anode. For amplification factors between 10^3 and 10^6, αd lies between 10 and 20.

Figure 4 from Christiansen 3) shows the shape of the pulse as a function of the input impedance and of the ion velocity. This fits our observations exactly.

The pulse shape on a high impedance load (1 MΩ) can be seen in Fig. 5a; only the component due to the drift of the positive ions is visible. On a much lower load, 5 kΩ, the pulse shape is the one shown in Fig. 5b and this fast component corresponds mainly to the electron avalanches.

With a threshold of detection of 500 μV, the time distribution of Fig. 6 has been measured for fast electrons, selected by a two-fold coincidence using the scintillation counters; the full width at half-maximum (FWHM) of the distribution is about 5 nsec, the full width at the basis being 15 nsec.

It must be stressed that the FWHM of the two scintillation counters alone, measured separately, was 1.5 nsec, thus giving a small contribution to the time jitter measurement on the PPC.

With reference to the scintillation counter coincidence, the efficiency of the chamber could then be measured; the results are given in Fig. 7 as a function of the high voltage. Owing to a small asymmetry in the PPC, the best results were obtained keeping HV1 and HV2 (see Fig. 3) separate. The plateau is about 100 V long for the lower threshold of 300 μV, and stops where occasional sparking has been observed. The time resolution in this measurement was kept large and fixed at 30 nsec for practical reasons (to avoid timing for each value of the HV).

The maximum efficiency in the plateau, as can be seen in the figure, is 95%; however, owing to the small sensitive surface of the chamber, this may well be just a geometrical effect and should be considered as a lower limit.

Of course the constant level discrimination is not necessarily the best method of detection.

Selecting only pulses in a given amplitude interval by means of a high-low discriminator arrangement, FWHM of 1 or 2 nsec were obtained. It is not clear at the moment if the high-low selection is simply a way of improving the timing by correcting for time slewing introduced by the differences in pulse heights, or if a selection on some physical properties of the PPC was done, which seems improbable.

We have no reason to expect an intrinsic time jitter greater than the one reached by spark counters, since the spark is a secondary effect following the development of avalanches and it seems to us that it is worth making an effort to understand the intrinsic lowest limit in the time resolution of these counters. It may be that it is lower than the one attainable with scintillation counters, since the structure is much more simple.

CONCLUSION

We have seen that with a proper gas mixture it is possible to operate a parallel-plate counter with efficiencies close to unity for minimum ionizing particles. The time resolution which we have reached in the first trial with primitive equipment, namely 5 nsec (FWHM), makes it an attractive detector whenever a small amount of matter is required, as for time-of-flight measurements of heavily ionizing particles.

These measurements offer an answer to the question: What limit can be reached with the wire spacing in multiwire proportional chambers? This limit is clearly zero. It is set only by the technical ability one has to weave a large number of wires per millimetre.

Since it is so difficult to go below a few wires per millimetre, why not make parallel-plate proportional chambers, with electrodes made of printed wires spaced by, say, 1/10 mm. Several analogic read-out methods could be used to identify the sensitive lines. We hope to determine the limit of accuracy that can thus be reached. It may result in the construction of detectors with a small superficial mass and a high spatial and time resolution. But despite the fact that it may be limited to small-area detectors, it may have important applications in the measurement of the momenta of high-energy pencil beams if time resolutions similar to those obtained with parallel-plate counters can be reached.

Acknowledgement

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2) V.V. Parchomtchouk, Ion. N. Pestov and N.V. Petrovitch, Institute of Nuclear Physics, Novosibirsk, Report I.Y.A.F. 70-55 (1970).

3) J. Christiansen, Z. Angewandte Phys. 4, 326 (1952).

Figure captions

Fig. 1 : Spark counter with a glass electrode. (Parchomtchouk et al., Ref. 2.)

Fig. 2 : Time resolution of the spark counter with a glass electrode. (Parchomtchouk et al., Ref. 2.) Histogram of the time jitter between two such counters.

Fig. 3 : Cross-section of the parallel-plate chamber (PPC). Active surface: 2 cm^2; gap: 2 mm.

Fig. 4 : Calculated pulse shape of parallel-plate chambers.
Left figure: infinite impedance load.
Right figure: variation of the pulse shape with different values of R_Z (impedance load) and R_E (input impedance of the amplifier). (From Christiansen, Ref. 3.)

Fig. 5 : Observed pulse shape
a) 1 MΩ load
Horizontal scale: 5 μsec/cm;
Vertical scale : 200 mV/cm.
b) 5 kΩ load
Horizontal scale: 50 nsec/cm;
Vertical scale : 2 mV/cm.

Fig. 6 : Time jitter spectrum in the parallel-plate chamber.
Decay-time spectrum between a scintillation counter and the chamber.
No amplitude selection.
Horizontal scale: 1 nsec/channel.
Argon - isobutane - methylal at atmospheric pressure.

Fig. 7 : Plateau of the parallel-plate chamber.
Minimum ionizing electrons.
The plateau value of 95% is a lower value.
Efficiency curves for a threshold value of 300 μV and 500 μV.
Argon - isobutane - methylal at atmospheric pressure.

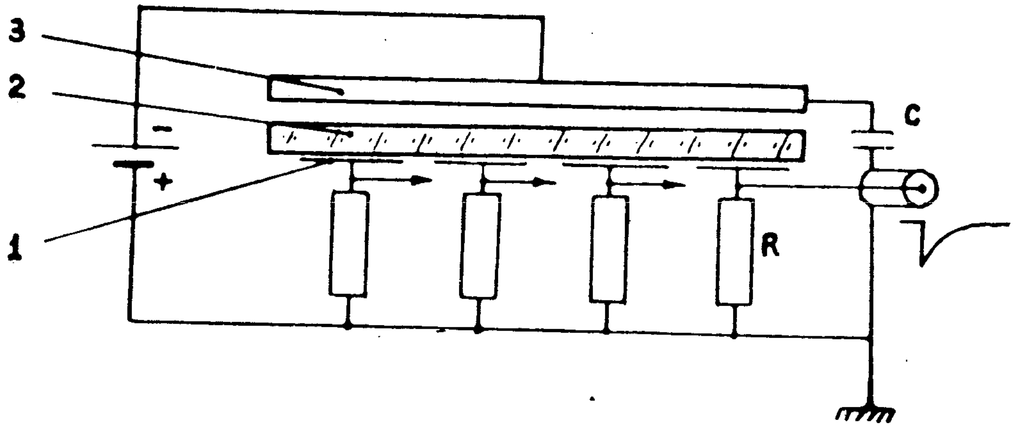


Fig. 1

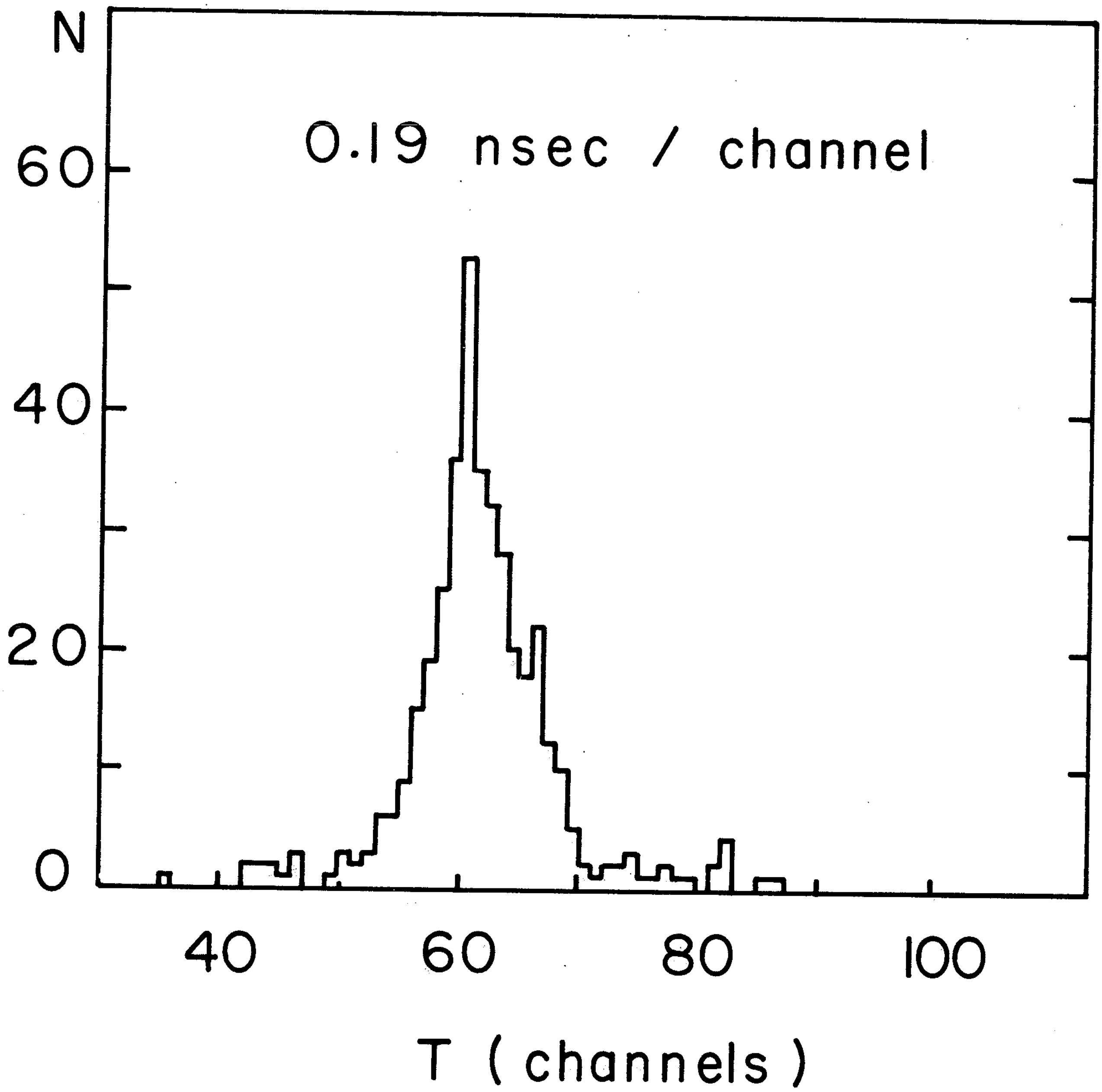


Fig. 2

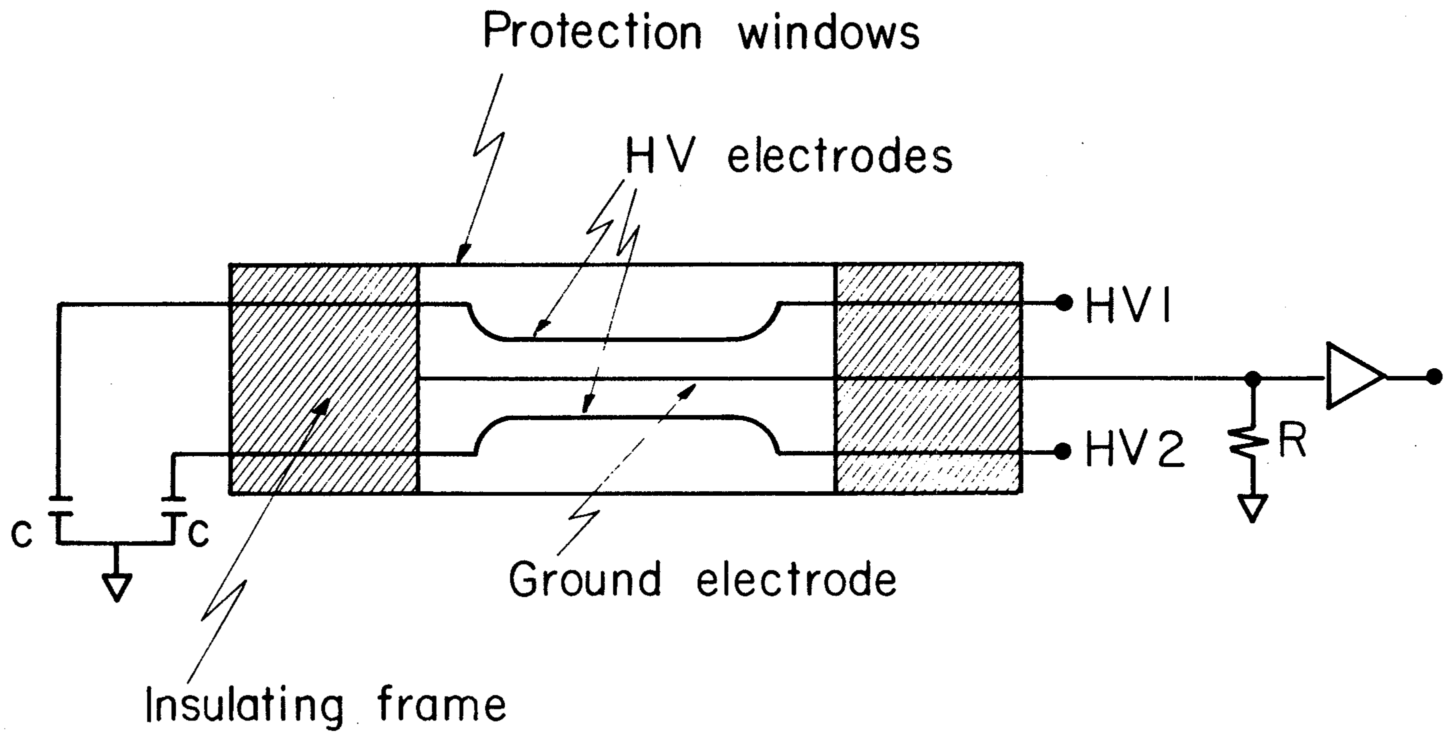

Protection windows
HV electrodes
HVI
HV2
R
c
c
Ground electrode
Insulating frame

Fig. 3

$$\Delta u_{ion} = \frac{N_0 e}{C_Z} \left(e^{\alpha d} - \frac{1}{\alpha d} e^{\alpha d} \right)$$

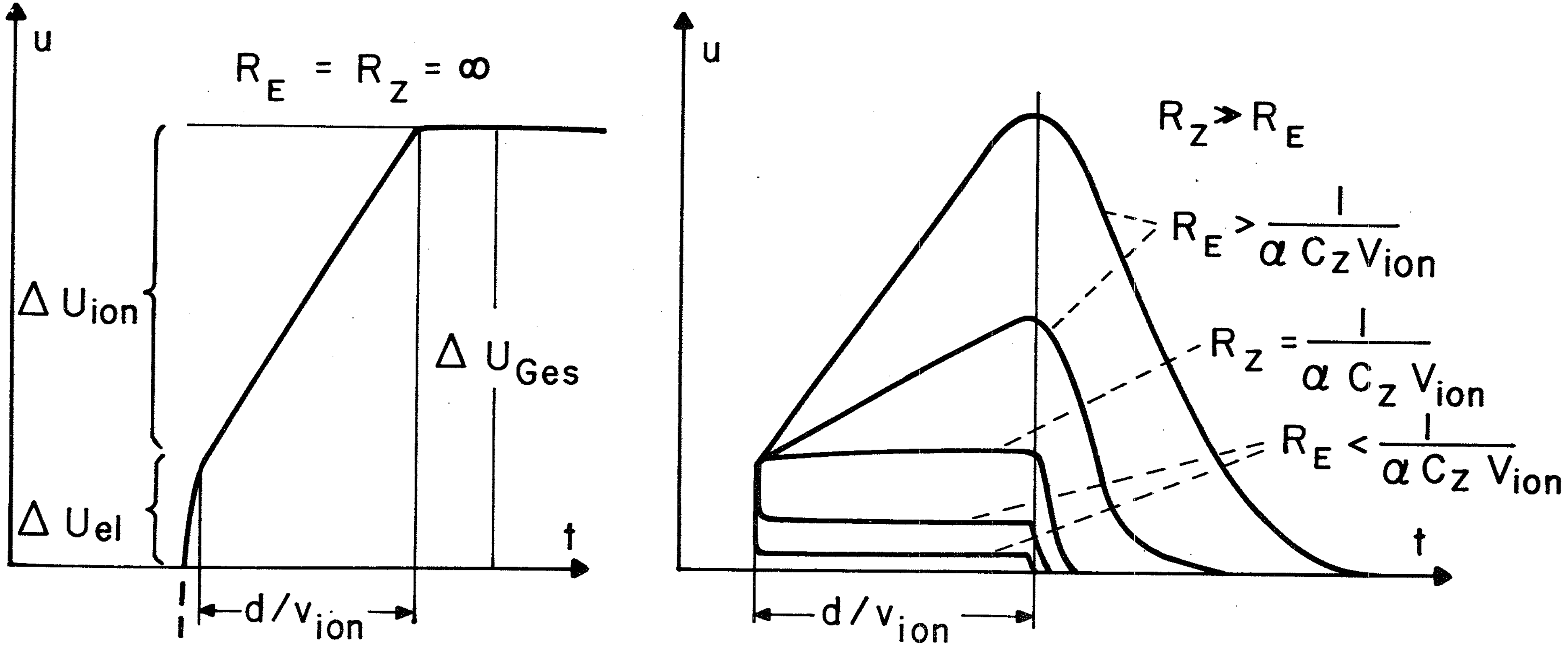
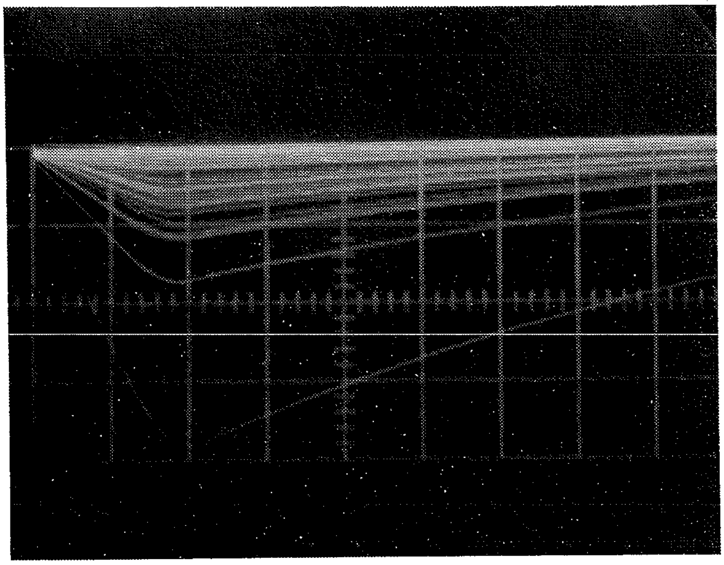
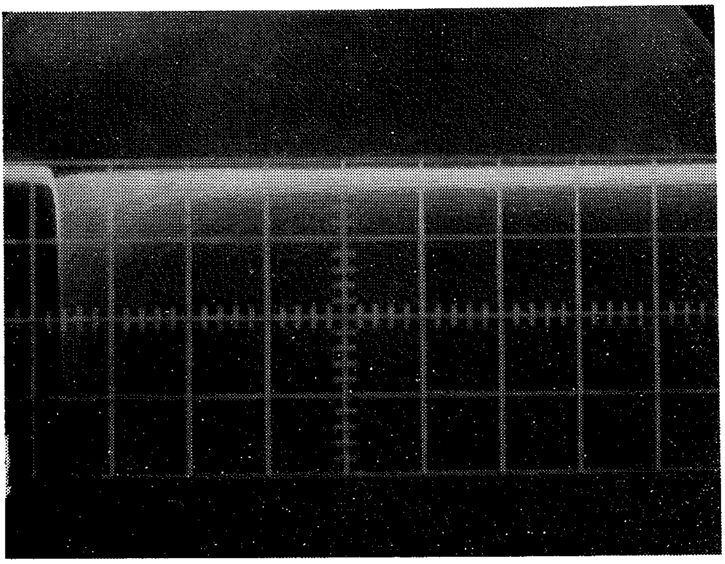


Fig. 4



a)



b)

Fig. 5

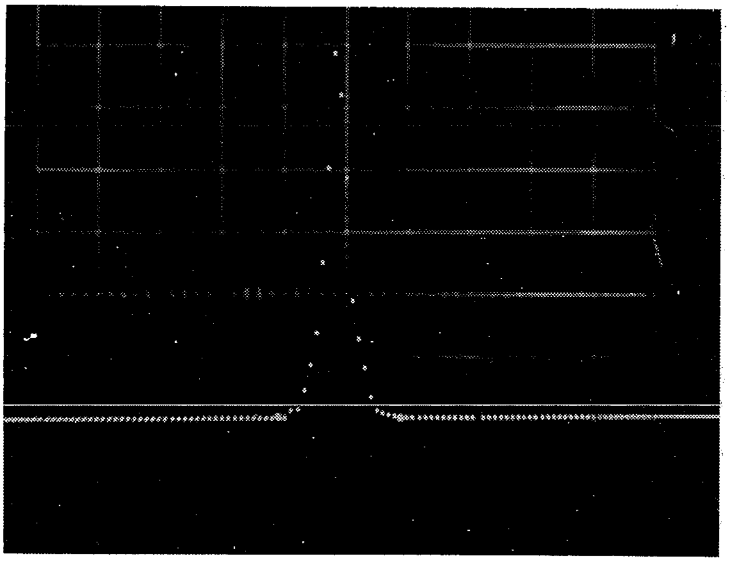


Fig. 6

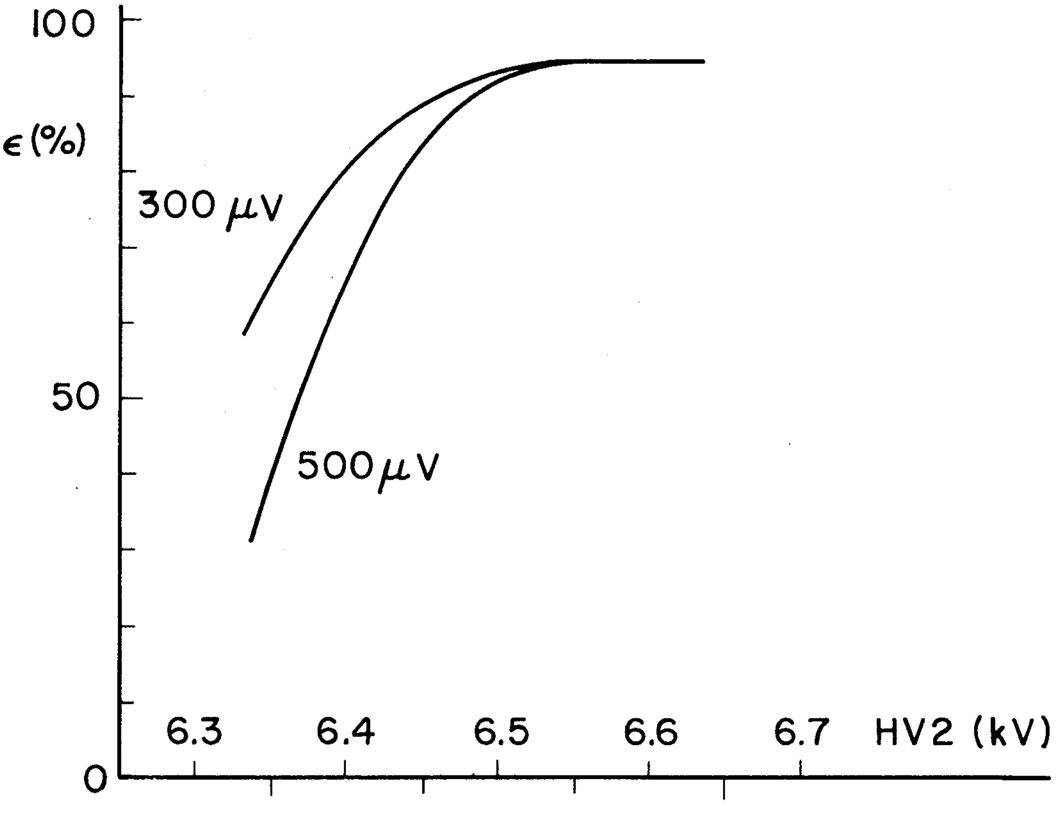


Fig. 7