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BREAKDOWN PROCESSES IN WIRE CHAMBERS AND PREVENTION

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Summary

Breakdowns were optically and electronically observed in drift tubes and drift chambers. They occur at a critical gain for given intensity in a gas mixture when ultraviolet photons are not completely quenched. It was observed that the breakdowns depended critically on average current for a given gas mixture independent of the size of the drift tubes used. Using 4.6% ethyl alcohol vapor mixed into 50/50 argon ethane gas, breakdowns are eliminated up to 7 μA average current drawn by pulses on a 1 cm section of an anode wire under an intense source.

Introduction

Operation of drift chambers and proportional chambers has been a painstaking struggle for many groups until the end of their experiments. For every case it took a learning period to accomplish satisfactory operation. Some people trained wires by allowing a small current for burning off contamination on cathode wires, some found certain gas mixtures improved the situation, some were able to operate at low gain by reducing pickup noise, thus increasing amplifier discriminator sensitivety, etc. In most cases, especially where beam rates were high, hot wires showed up in a random way. These hot wires had to be replaced or cleaned or disabled. Unfortunately no one has written a few paragraphs to explain what helped them for satisfactory operation. For this reason no references can be given for the above cases. All information was obtained by friendly private communications.

Most of the problems may have been due to arbitrary chamber designs and casual selection of gases. One took someone elses design, because that worked. It may have worked with certain gain and for certain rates, but it may have failed at higher beam intensities. Detailed studies of breakdown processes in gases were done[1] earlier using mainly parallel plate geometry. There has been no methodic study of breakdowns with very commonly used gases in multiwire drift chambers or drift tubes.

This paper is the result of some systematic studies of breakdown processes and prevention of chamber breakdowns related to beam rate and gain.

a. Breakdown in drift tubes

The following tests were carried out to help understand intensity and gain related breakdown processes in wire chambers. For simplicity two aluminum tubes of different sizes, a conductive plastic tube[2] and a small drift chamber with a few wires were used for the tests. All the tubes and the chamber had transparent windows for optical observation. These windows were made of In-Sn Oxide transparent film on mylar.[3] The film is sufficiently conductive to serve as a cathode material. The aluminum tubes were 9.5 x 9.5 mm^2 and 12 x 12 mm^2 cross-section, and the conductive plastic tube was 7 mm x 10 mm. Configuration of the drift chamber is shown in Fig. 1. The anode wires in the tubes and of the chamber were 50 μm thick gold plated tungsten. The gas mixture for these tests was 50/50 percent premixed (by volume) argon-ethane flowing through ethyl alcohol (CH_3CH_2OH) at 0°C at a rate of 200 cc/min.

A narrowly collimated (large fraction of the intensity within 5 mm diameter circle) Sr^{90} source of 1 mCi strength was held at a short distance from the tubes. Intensity of the source was regulated by aluminum shim absorbers.

As shown in Figs. 2-a,b and c, independent of the source position along the wires in the tubes, a spontaneous breakdown occurred at a critical gain and a critical intensity. It occurred randomly within a minute (from a few seconds to a minute). Thus the points were taken at three minute intervals. The manifestation of the breakdown is a sudden increase in the high voltage power supply current that slowly reaches to a value around 10 μA which is limited by the gas impedance (there was no current limiting resistor in the circuit). This current is sustained until the high voltage is lowered considerably.

Average dc current drawn through the power supply was monitored. An interesting fact is that the current was approaching 0.4 to 0.5 μA when the breakdown occurred independent of the tube size and intensity. The conclusions from the results are that the breakdown is critically dependent on total average current (i.e., gain x intensity) for this collimation of the source illuminating mainly 1 cm of the anode wire, and the value of the current is 0.5 μA for this gas mixture. It is an important matter to note here that after so many breakdowns the wires held the voltage values at the intensities given. The wires and the cathode surfaces were examined under a microscope showing no observable damage. The gain characteristics of the 9.5 mm x 9.5 mm tube is given in Fig. 3 using a Fe^{55} source to get an idea about the gain values for Fig. 2a. Primary ionization characteristics of the Sr^{90} source is rather different; Sr^{90} results in a wide range of primary specific ionization.

As an exercise let us take Fig. 2a. Breakdown voltage is around 2.4 kV for the source intensity of 1.25×10^5 sec^{-1}. The gain value obtained from Fig. 3 for 2.4 kV is 10^5. 0.5 μA average dc current corresponds to 5×10^{-7} Coulomb of charge. This is $\sim 3.1 \times 10^{12}$ electrons. An average avalanche size (number of total electrons after multiplication) per track is

$$\frac{3 \times 10^{12}}{1.25 \times 10^5} \simeq 2.4 \times 10^7 \text{ electrons.}$$

Then the average primary ionization per track is

$$\frac{2.4 \times 10^7}{10^5} = 240 \text{ electron-ion pairs.}$$

This is a reasonable number for the source.

The same tests were attempted with the small drift chamber using the same gas mixture and the same source strength. No breakdown up to 7 μA dc at 3.1 kV applied voltage was found. Self quenching streamers showed up at a voltage around 2.6 kV and at 3.1 kV mainly streamers were observable.

b. Optical observations

Using an image intensifier video camera described in an earlier paper,[4,5] photons from the active area were observed while the average dc current was measured as a function of applied high voltage. Pulses from the anode wires were also observed to detect streamer transitions when the applied voltage was sufficiently high. High voltage versus measured current characteristics is shown in Fig. 4. Space charge saturation begins at 2.3 kV (avalanche saturation). The streamer threshold is around 2.75 kV.

Photon activity around the anode wires of the drift chamber makes the wires visible as shown in Figs. 5a, b and c. The source rate was $\sim 10^5$ counts for each wire per second. The higher the gain the more photons are detectable. Some short streamers are visible at 2.8 kV (Fig. 5b). Many more can be seen at 3.1 kV (Fig. 5c). These and further pictures are the negatives of the polarized photographs for better visibility in copying processes. The photographs are 1/20th second time exposed pictures taken from a video monitor. The author believes that these photons come from some recombination processes not from normal avalanche processes. A hint for this is at low rates (less than 10^4/sec) only streamers can be seen when the voltage exceeds 2.7 kV; no photons could be detected below the streamer transition. A large number of photons are emitted from the space surrounded by cathode wires when the source intensity is high and the gas gain is sufficiently high, and the space is filled by an ion cloud. Even then no breakdown, (i.e., no sustained activity) was observable up to 3.1 kV with the gas mixture when the source was pulled away.

c. Breakdown in the drift chamber

This time the 1.4% ethyl alcohol component of the gas mixture was removed; only 50% A - 50% C_2H_6 mixture was used. The β-source was kept at the same place from the chamber, thus providing about 10^5 counts per second per wire over mainly 1 cm of length. In this case, wires were visible at 1.8 kV. A boiling hot circle appeared (Fig. 6) at 1.9 kV. The circle became very visible at 2.1 kV and it stayed active when the source was pulled away. The high voltage had to be lowered below 1.8 kV for the active circle to disappear. This and other phenomena will be explained further in the paper. The applied voltage was turned off and increased each time the hot spot appeared (at the same place). Each subsequent discharge appeared at successively lower voltages. Thus the first breakdown left a scar on the wires and it was getting worse at each repeated breakdown. Figure 7 shows the relation between the average dc current and the applied voltage. The breakdown current of 0.31 μA is interestingly close to what was found with the tubes previously.

The above results indicate that CH_3CH_2OH is an important element in the gas mixture in preventing the breakdown and probable surface damages related to intensity and gain.

d. <u>Preventing breakdowns in the conductive plastic tube</u>

More tests were carried out for understanding the effectiveness of the ethyl alcohol component in the A - C_2H_6 gas mixture in preventing breakdowns mentioned in the previous sections. The conductive plastic tube was chosen for the following experiments because of its small size (7 mm gap).

As explained in the previous sections, breakdowns did occur at critical gains and critical intensities (Fig. 2c) with the conductive plastic tube in the gas mixture of 49.3% A - 49.3% C_2H_6 - 1.4% CH_3CH_2OH, but there was no breakdown in the drift chamber until the ethyl alcohol vapor was removed. To help understand these phenomena, the ethyl alcohol vapor concentration was varied from 0 to 4.6% and breakdown current was measured with a source intensity exceeding 1.5×10^5 pulses per second. The results are shown in Fig. 8. Breakdown current is very low (around 0.1 μA) without CH_3CH_2OH and the breakdown is practically eliminated with 4.6% CH_3CH_2OH in the gas mixture. There was no breakdown up to 7 μA. This is a very respectable current (i.e. gain x rate per second), therefore no attempt was made beyond this intensity and the gain.

It was clear from the results above that ethyl alcohol did enable the tube run at much higher gain without breakdown. Then the next logical experiment was to study other alcohol vapors, namely, methanol (CH_3OH) and isopropanol ($(CH_3)_2$ CHOH). Figure 9 shows partial vapor pressures of the alcohols mentioned as a function of temperature. The numbers are taken from "Handbook of Chemistry and Physics". From these curves we find that we need to keep CH_3OH at 3°C and $(CH_3)_2$ CHOH at 35° C to have 4.6% of each in the A - C_2H_6 mixture. Clearly, the latter was found not to be practical. Tests also showed that bubbling A - C_2H_6 through $(CH_3)2$ CHOH at room temperature was not sufficient for preventing the breakdown. CH_3OH had to be kept around 10°C to be effective. This may be due to the reason that CH_3OH is a less complex molecule than CH_3CH_2OH, and thus would have less rotational and vibrational absorption levels for quenching ultraviolet photons which could reach the cathode and knock out electrons. CH_3CH_2OH should also be preferred because it is not an active vapor for plastics, epoxy, etc.

Optical studies also confirmed the results above. Some details are given in the next section.

e. Optical observation of Geiger Mode

The conductive plastic tube was studied through the image intensifier camera to gather more information about the breakdown processes. As discussed in the previous sections, breakdowns could occur in the tube when the ethyl alcohol concentration in the argon-ethane gas mixture was below 4.6%. Such a breakdown was observed on the video display. Bright spots around the anode wire showed up. After a few seconds more bright spots appeared and then the brightness spread quickly all along the wire. At this time about 10 μA current was drawn through the high voltage power supply even though the source was pulled away. It continued until the voltage was lowered below 1.5 kV. This sequence is shown in Fig. 10a,b and c. Interestingly, the holding voltage of the wire stayed the same after many breakdown tests even after allowing 10 μA of breakdown current to continue for more than 10 minutes with the existence of ethyl alcohol vapor in the gas mixture. After the tests, surfaces of the anode and cathode were examined under a microscope and no visible damage was found.

Is this a true Geiger mode? This question will be discussed further in the paper. There was no observable breakdown on the screen when 47.7% A - 47.7% C_2H_6 - 4.6% CH_3CH_2OH gas mixture was used. Figure 11a and b show the photon activity around the wire at currents of 0.7 and 3 μA, respectively. Figure 11b shows projections of the self-quenching streamers around the anode wire.

The Geiger mode-like spread along the anode wire of the conductive tube could not be seen in the aluminum tubes. The breakdowns were around local spots. A reason for this may be due to the aluminum tubes being considerably larger in size. All the evidence found with this and earlier work[5] indicate that breakdown spread along the wire is mediated by electrons knocked out of the cathode walls by ultraviolet photons, unlike the well known Gieger operation.[6]

f. Epoxy droplets on cathode wires affect operation of the drift chamber

Some cathode wires of the beam drift chamber (mentioned in Sections a and c) were smeared with epoxy which formed droplets around the wires as shown in Fig. 12. Optical observation on the video display showed that at 2.2 kV (0.16 μA) a hot spot on the wire appeared with 1.6% ethyl alcohol in the gas mixture and it got brighter at 2.7 kV (2 μA) seen in Fig. 13. The hot spot disappeared when the source was pulled away. The position of the spot was in the region where the epoxy droplets were. This could not be observed under the same conditions given above when the same anode wire plane and a clean cathode wire plane were used. A probable explanation for this phenomenon is that the epoxy charges up with the positive ions, polarizes and becomes an electron ejector (Malter Effect). If this is so it could explain why the spot disappeared when the high flux of positive ions stopped (removing the source).

g. <u>More boiling hot circles</u>

It was discussed in Section c that circles showing boiling-like activity in the drift chamber were observed with the image intensifier camera using 50% A - 50% C_2H_6 gas mixture and this breakdown condition was completely prevented by the addition of ethyl alcohol vapor. The tests were done with a newly wired chamber frame. This time identical wire planes of a damaged beam drift chamber were used for the tests. The chamber had some breakdowns while operating with the A - C_2H_6 gas only. There were clearly seen scars on the anode wires.

Hot spots were observed in this chamber up to an ethyl alcohol concentration of 3.3% in the gas mixture. Figure 14a shows the hot spots around the anode wire with the β-source illuminating the chamber (breakdown current of 3 μA). Figure 14b shows that the hot spots remained after removing the source. A boiling circle showed up near the cathode that feeds one of the hot spots on the anode when the camera's sensitivity was increased (Fig. 14c). Hot spots completely disappeared when 4.6% alcohol vapor was used, as seen in Fig. 14d. The conclusion is that even a damaged chamber can be successfully used when complete UV quenching is achieved.

h. Some hints from the experimental results

The following conclusions can be summarized on breakdowns and their prevention from the experimental results given in this paper:

1. The breakdown is strongly dependent upon the average current for a given gas mixture (i.e., higher gain for smaller beam rate).

2. The current = gain x primary ionization x rate can be increased with additional quenching vapor.

3. For all types of the chambers examined here ethyl alcohol, CH_3CH_2OH is an excellent quencher in reducing breakdown probability. 4.6% ethyl alcohol vapor in 47.7% A - 47.7% C_2H_6 mixture appeared to be sufficiently good quenching gas for currents up to 7 μA without any breakdown, even with damaged wires.

4. Epoxy droplets may produce hot spots on anode wires.

5. In conductive plastic tubes of 7 mm size, a Geiger-like mode was observed.

6. There was no detectable damage on the anode or cathode surfaces after successive breakdowns using the Ar - C_2H_6 - CH_3CH_2OH gas mixture.

7. A lifetime test was made with the drift chamber using 49.2 A - 49.2% C_2H_6 - 1.6% CH_3CH_2OH and a high flux Sr^{90} β-source. There was no detectable damage on the wires for integrated pulses of 10^{11} with a gain of 10^5. This amounts to a total of 2.4 x 10^{18} electrons/cm on the wires (see Section a).

8. Electron drift velocity is affected by the addition of ethyl alcohol vapor. This remains to be measured in a systematic way.

9. Last, but not least, there is a great deal more to be learned on the subject.

i. Breakdown processes

Some explanations can be given on how and why breakdowns occur in wire chambers or drift tubes using the results given in this and the earlier paper.[5] These explanations may be supplementary to the work edited by H. Raether[1] for the parallel plate configuration.

1. In the avalanche process, a critical charge density

is reached before the streamer action so that radiative recombination can occur.[5]

2. What makes the streamer grow is most probably a reproduction of electrons near the streamer head by the recombination photons.

3. Another probable way of streamer growth may also occur when a highly intense beam or source is used. Coincidentally, some electrons happen to be present from another track near the tip of an avalanche cone although the critical charge density may not have been reached for regeneration of electrons by the radiative recombination photons. These accidental electrons could in succession enable the avalanche to grow into a full streamer. The streamer may grow close to the cathode. When this happens electron regeneration from the cathode could follow by the photons knocking out electrons. This condition could end up with a continuous feedback from the cathode as found in the breakdown conditions when the quenching was insufficient. This feedback mechanism continues even after removing the source (Sections c and g). Figure 15 shows some of these cathode electrons fed back breakdown circles dramatically (boiling circles).

Interestingly, the circles are identical in size, about 3.6 mm in diameter (real size). Top views of some of the individual self quenching streamer pictures[5] very much resemble the circles (Fig. 16).

If this is all correct then the anode cathode separation and cathode configuration play an important role in electron regeneration by photons from cathode surfaces. Wire cathode configuration reduces the probability of such photoelectron production, thus it should be preferred relative to continuous cathode coverage (simple solid angle consideration). Work function of the cathode material may also play an important role in this matter.

Conclusions:

A suggestion resulting from this work is that one should do a careful study of gain characteristics of a chamber designed for a specific purpose under an intense source using a gas mixture to match with electronics (mainly amplifier- discriminator circuits). It should not be assumed that even for relatively low intensities one can increase gain arbitrarily.

One should not allow breakdown to occur without a protective vapor like ethyl alcohol, otherwise scars may be left on anode and cathode surfaces. Some tests were done using 70% argon 30% isobutane (instead of ethane) mixture bubbling through ethyl alcohol at temperatures up to 17°C, adding about 4.6% alcohol to the mixture, using the conductive plastic tube. Every breakdown left damage on the anode and the cathode surfaces, thus high voltage had to be lowered. Why couldn't the alcohol prevent breakdown with isobutane mixture and damages? This should be investigated.

Acknowledgement

The author would like to express his appreciation to Dr. M. Mishina for many discussions on the subject.

References

1. H. Raether, Electron avalanches and breakdown in gases, Washington Butterworths (1964).
2. M. Atac et al., IEEE Trans. on Nucl. Sci., Vol. NS-29, No. 1 (1982) 368.
3. M. Atac, Nucl. Inst. and Meth. 176 (1980) 1-8.
4. M. Atac and A. Tollestrup, Fermilab Report, FN-337 (1981).
5. M. Atac, A. Tollestrup and D. Potter, Nucl. Inst. and Meth. 200 (1982) 345-354.
6. S. A. Korf, Electron and Nuclear Counters (Van Nostrand 1955).

Figure Captions

Fig. 1 - Cross section view of the drift chamber.

Fig. 2a - Breakdown curve for 9.5 x 9.5 mm^2 size aluminum drift tube. Independent of source position along the wire there was a breakdown at a critical high voltage (i.e., gain) at the given intensity when average current reached around 0.5 μA. The gas mixture was 49.3% A - 49.3% C_2H_6 - 1.4% CH_3CH_2OH.

Fig. 2b - Same as 2a for 12 x 12 mm^2 size aluminum tube.

Fig. 2c - Same as 2a for 7 x 10 mm^2 size conductive plastic tube.

Fig. 3 - Gain characteristics of the 9.5 x 9.5 mm^2 aluminum drift tube in the saturated avalanche and streamer regions.

Fig. 4 - Gain characteristics of the drift chamber using the high intensity Sr^{90} β-source of 10^5 pulses/sec for 1 cm wire. The gas mixture is 49.3% A - 49.3% C_2H_6 - 1.4% CH_3CH_2OH.

Fig. 5 - Photon activity around the anode wires of the drift chamber at 2.5, 2.8 and 3.1 kV. The pictures are negatives of the photographs taken from the video display of the image intensifier camera.

Fig. 6 - Hot breakdown circle in the drift chamber when the ethyl alcohol component of the gas mixture was removed. Diameter of the circle is about 3.6 mm. It remained there even after removing the source.

Fig. 7 - Average current as a function of the applied voltage with the existence of the breakdown circle shown in Fig. 6. There was no ethyl alcohol vapor in the drift chamber.

Fig. 8 - Breakdown current as a function of ethyl alcohol concentration in A - C_2H_6(50/50) for the conductive plastic tube. It shows that no breakdown occurred up to 7 μA when the ethyl alcohol concentration was 4.6%.

Fig. 9 - Vapor pressure curves of ethyl, methyl and isopropyl alcohol as a function of temperature.

Fig. 10 - (a) Hot spots on the anode wire of the conductive plastic tube when the gain is above a critical value for the hot source (see Fig. 2c). 1.5% ethyl alcohol in the gas.

(b) More hot spots appear after a moment.

(c) Geiger-like spread along the wire.

Fig. 11 - Breakdown was eliminated in the conductive plastic tube by 4.6% ethyl alcohol in the A - C_2H_6 (50/50) gas mixture up to streamer operation with the hot source. (a) Photon activity at 0.7 μA, (b) streamer photons at 3 μA.

Fig. 12 - One of the cathode wire planes of the drift chamber with epoxy droplets which were deliberately smeared on the wires for the study.

Fig. 13 - A hot spot on the anode wire of the drift chamber in the vicinity of the epoxy droplets. Gas mixture contains 1.6% ethyl alcohol. HV = 2.7 kV. Average current was 2 μA.

Fig. 14 - An identical drift chamber with damaged wires. (a) hot spots on the anode wire even with 3.3% ethyl alcohol vapor in the gas; (b) hot spots remain after removing the source; (c) showing one of the hot spots that was fed by a boiling circle near the cathode wires; (d) hot spots could not be observed with 4.6% ethyl alcohol in the gas.

Fig. 15 - Breakdown circles and hot spots on the anode wire of the drift chamber more dramatically seen when the ethyl alcohol was removed from the gas mixture. (a) The source is on, (b) source is off. At a rather low HV = 2 kV and 2.1 kV, average current is around 0.12 μA.

Fig. 16 - (a) A pair of branched streamers grown like a cone with the cathode fed electrons knocked out by ultraviolet photons. (b) An imaginary cone around (a). Top view of the cone is about the same size as the hot circles.

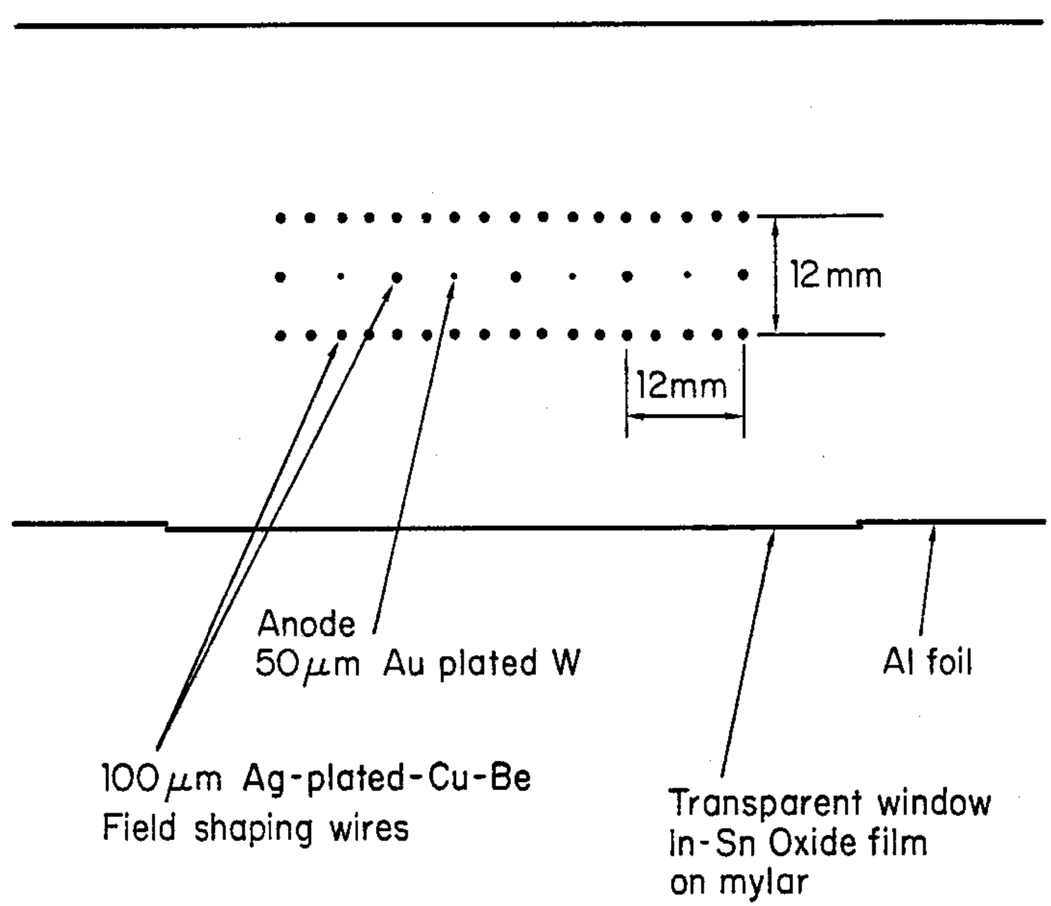

12 mm
12mm
Anode
50μm Au plated W
Al foil
100μm Ag-plated-Cu-Be
Field shaping wires
Transparent window
In-Sn Oxide film
on mylar

Fig. 1

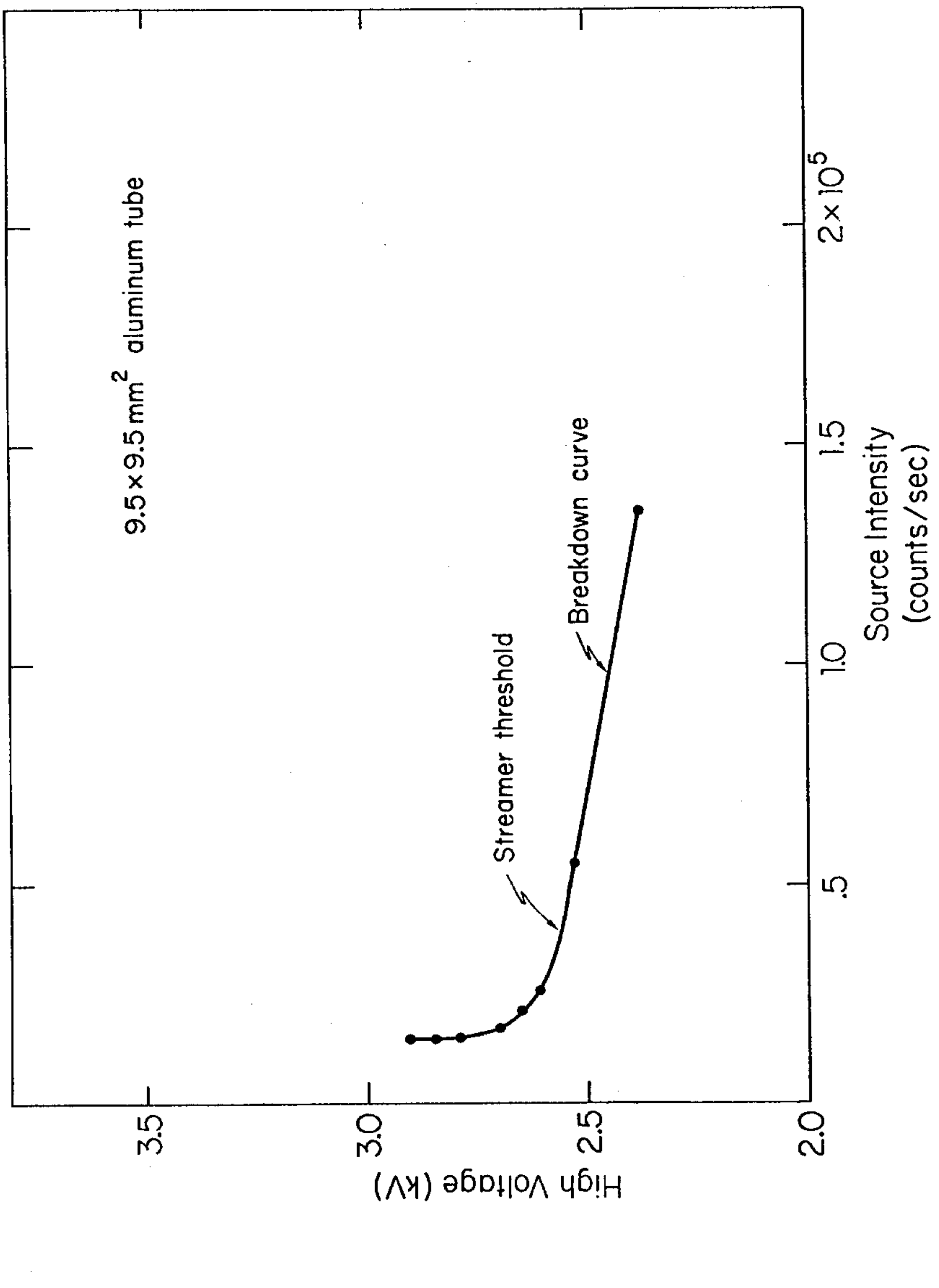

9.5×9.5 mm² aluminum tube
Streamer threshold
Breakdown curve
High Voltage (kV)
2.0
2.5
3.0
3.5
Source Intensity (counts/sec)
.5
1.0
1.5
2×10⁵

Fig. 2a

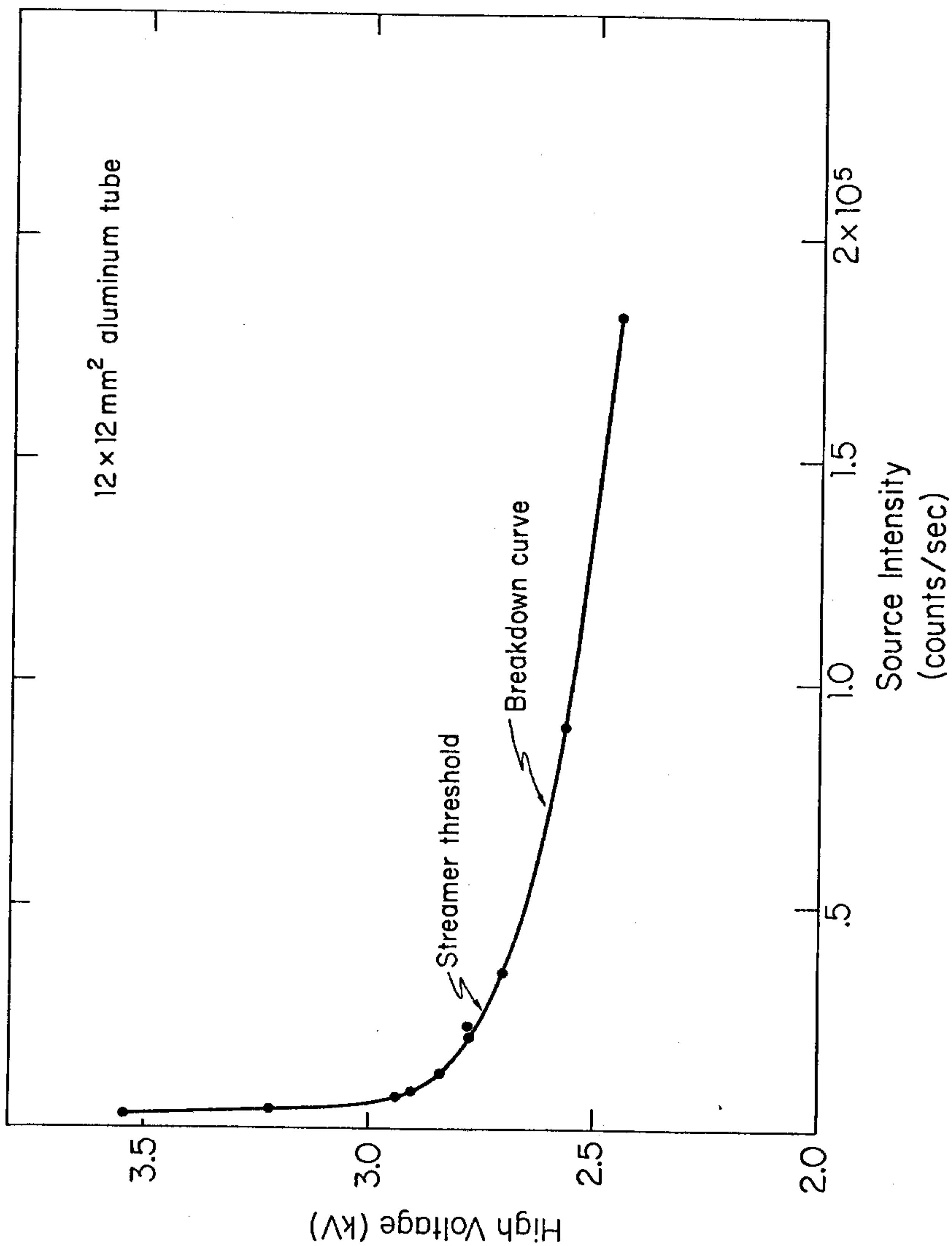
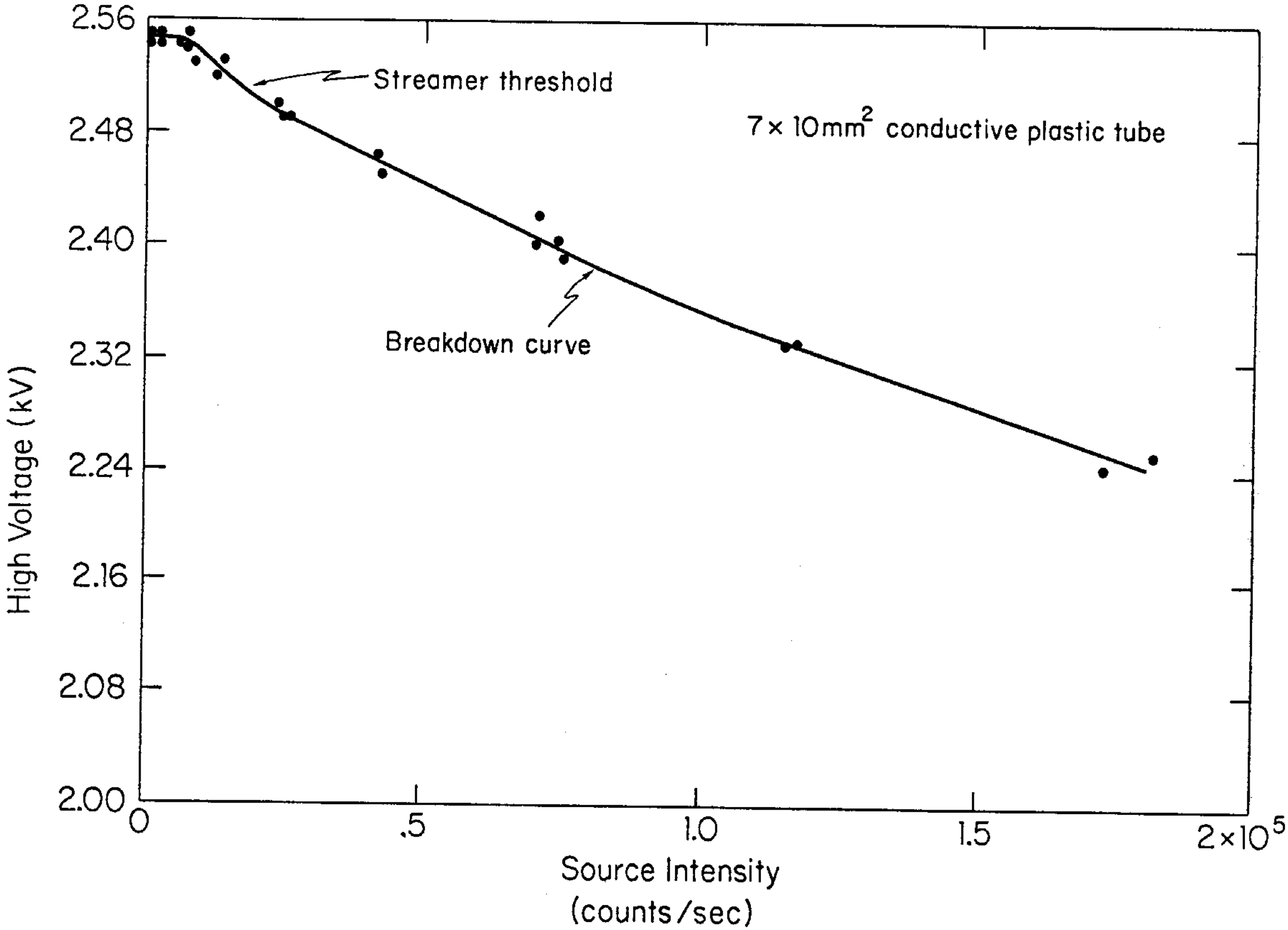

12 × 12 mm² aluminum tube
Breakdown curve
Streamer threshold
High Voltage (kV)
2.0
2.5
3.0
3.5
Source Intensity (counts/sec)
.5
1.0
1.5
2 × 10⁵

Fig. 2b



Streamer threshold
7 × 10mm² conductive plastic tube
Breakdown curve
High Voltage (kV)
2.56
2.48
2.40
2.32
2.24
2.16
2.08
2.00
0
.5
1.0
1.5
2×10⁵
Source Intensity
(counts/sec)

Fig. 2c

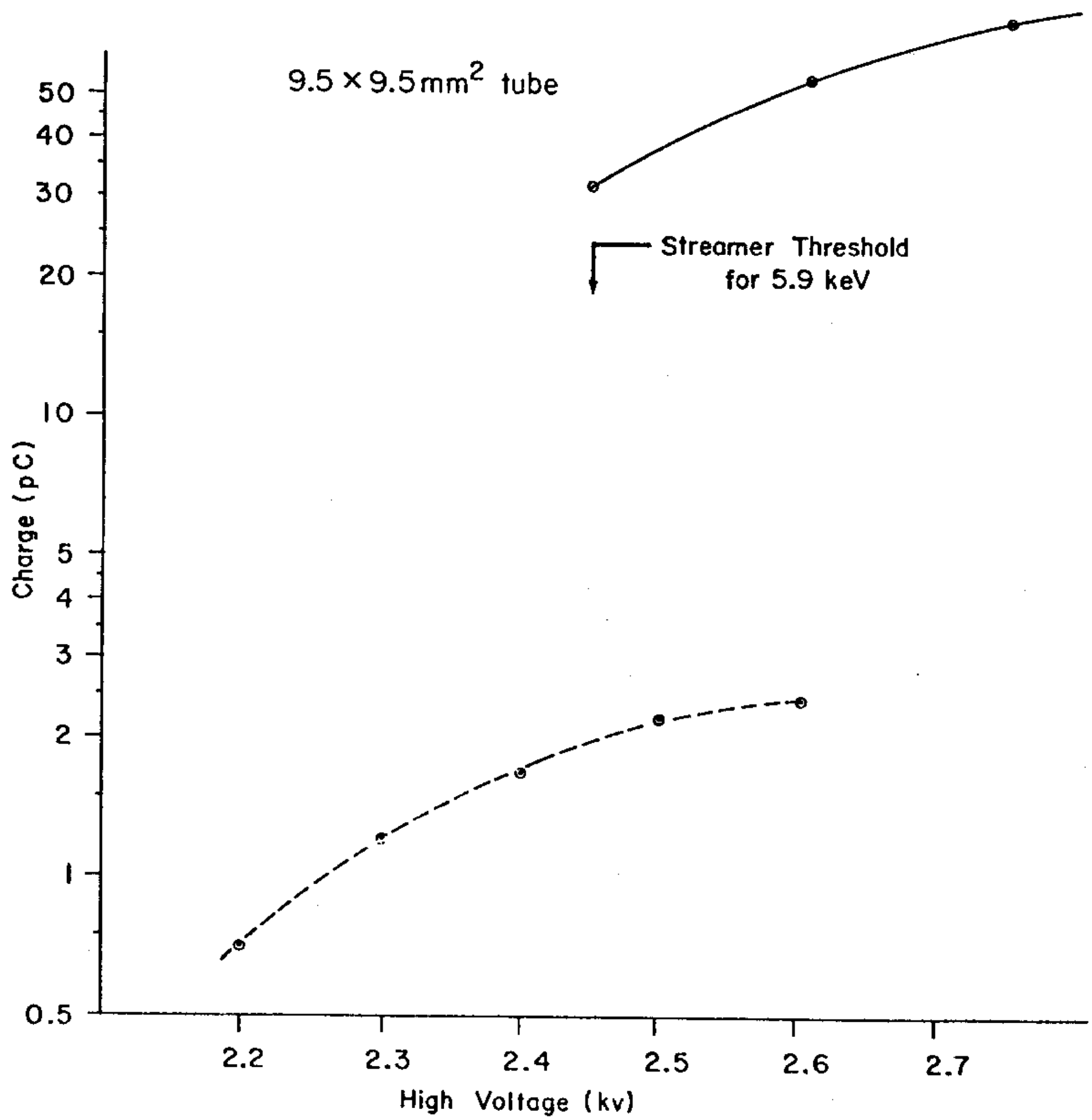

9.5 × 9.5 mm² tube
50
40
30
20
10
5
4
3
2
1
0.5
Charge (pC)
Streamer Threshold
for 5.9 keV
2.2
2.3
2.4
2.5
2.6
2.7
High Voltage (kv)

Fig. 3

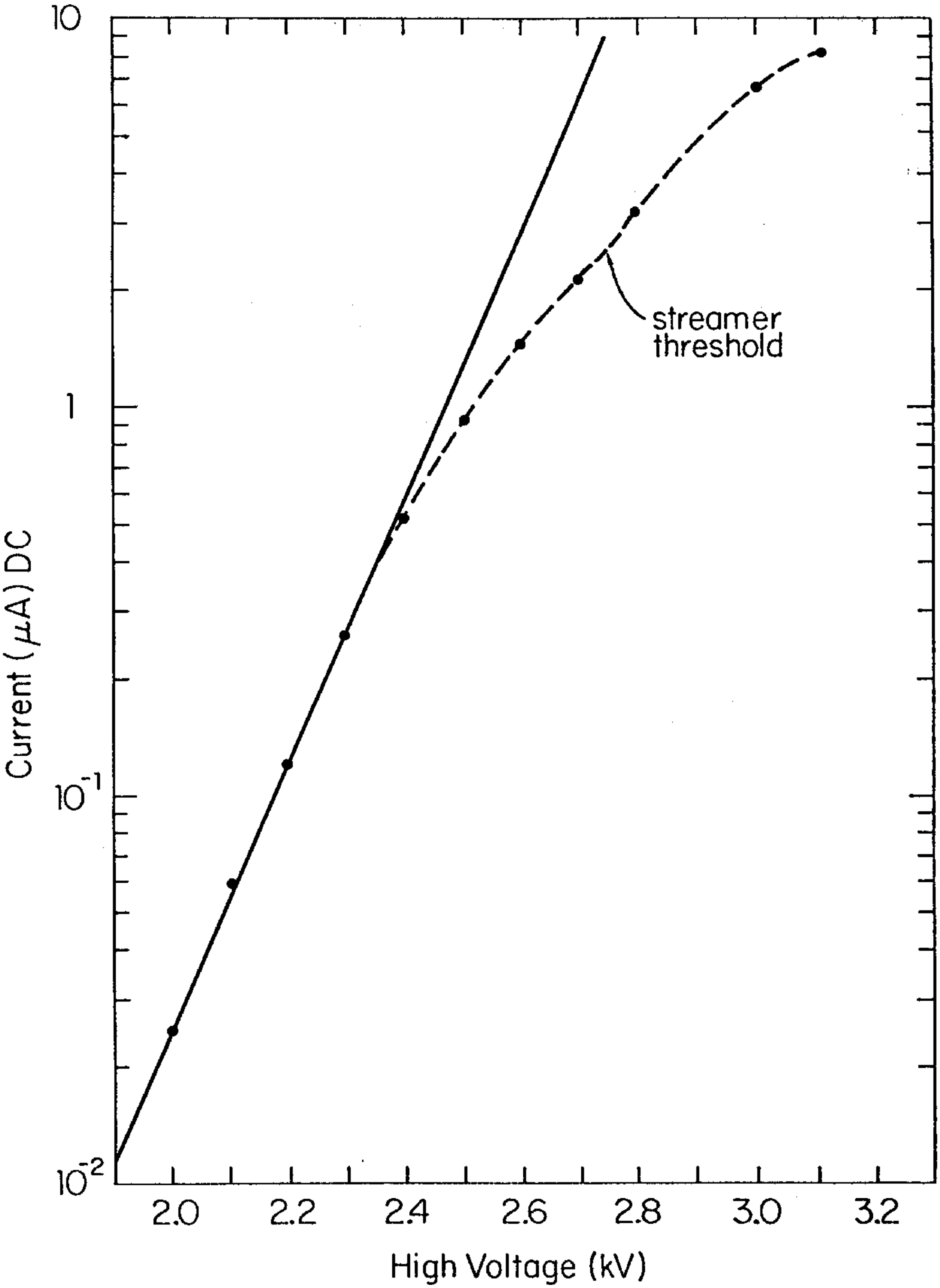
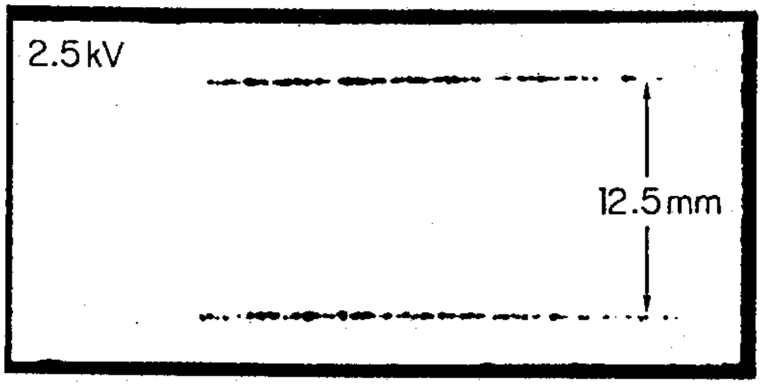

10
1
10^{-1}
10^{-2}
Current (μA) DC
streamer
threshold
2.0
2.2
2.4
2.6
2.8
3.0
3.2
High Voltage (kV)

Fig. 4



(a)

(b)

(c)

Fig. 5

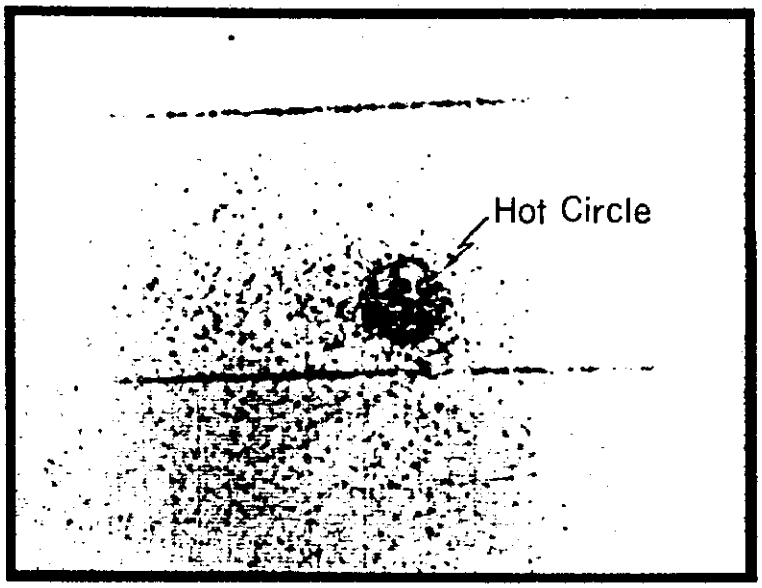


Fig. 6

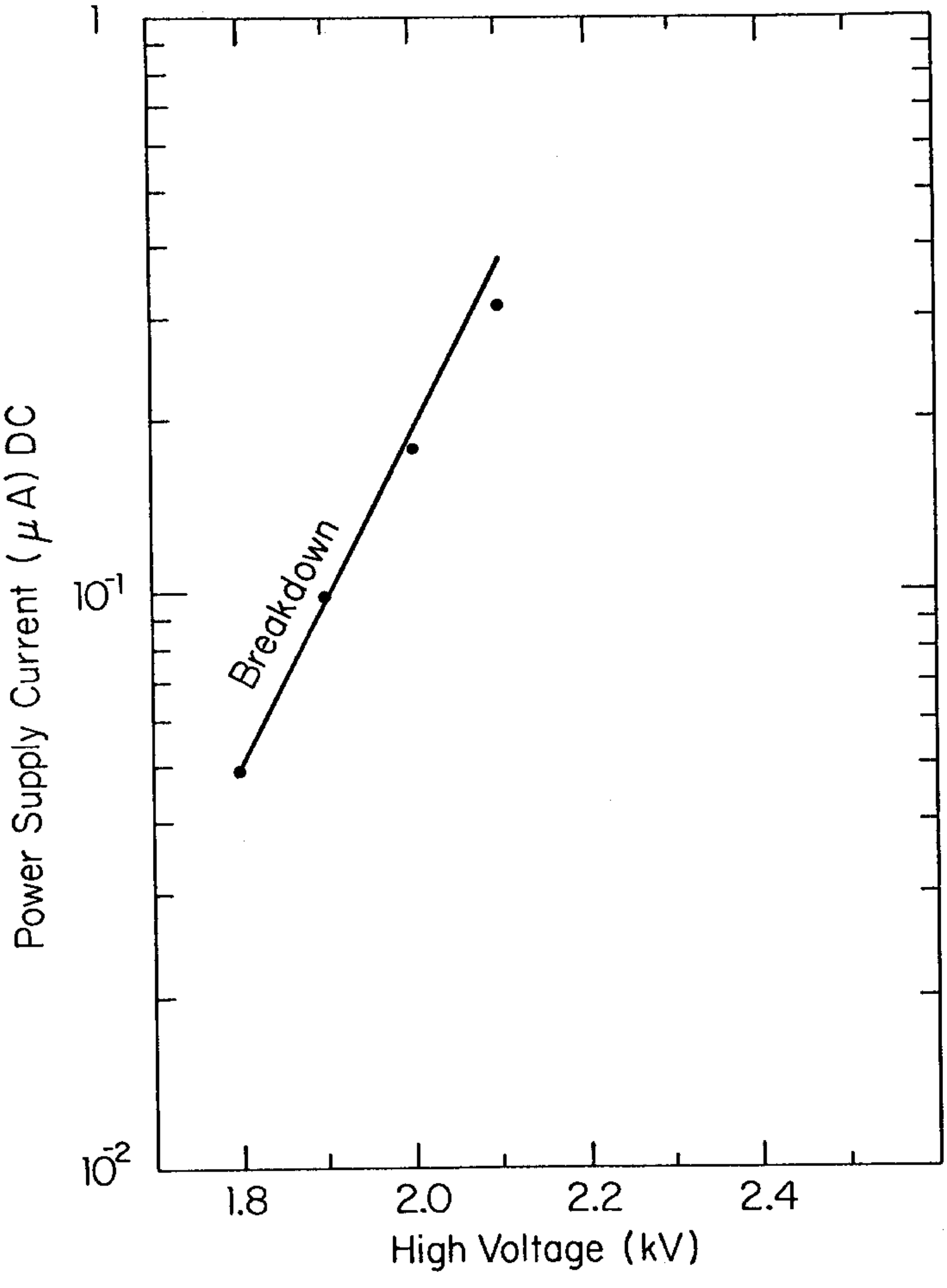
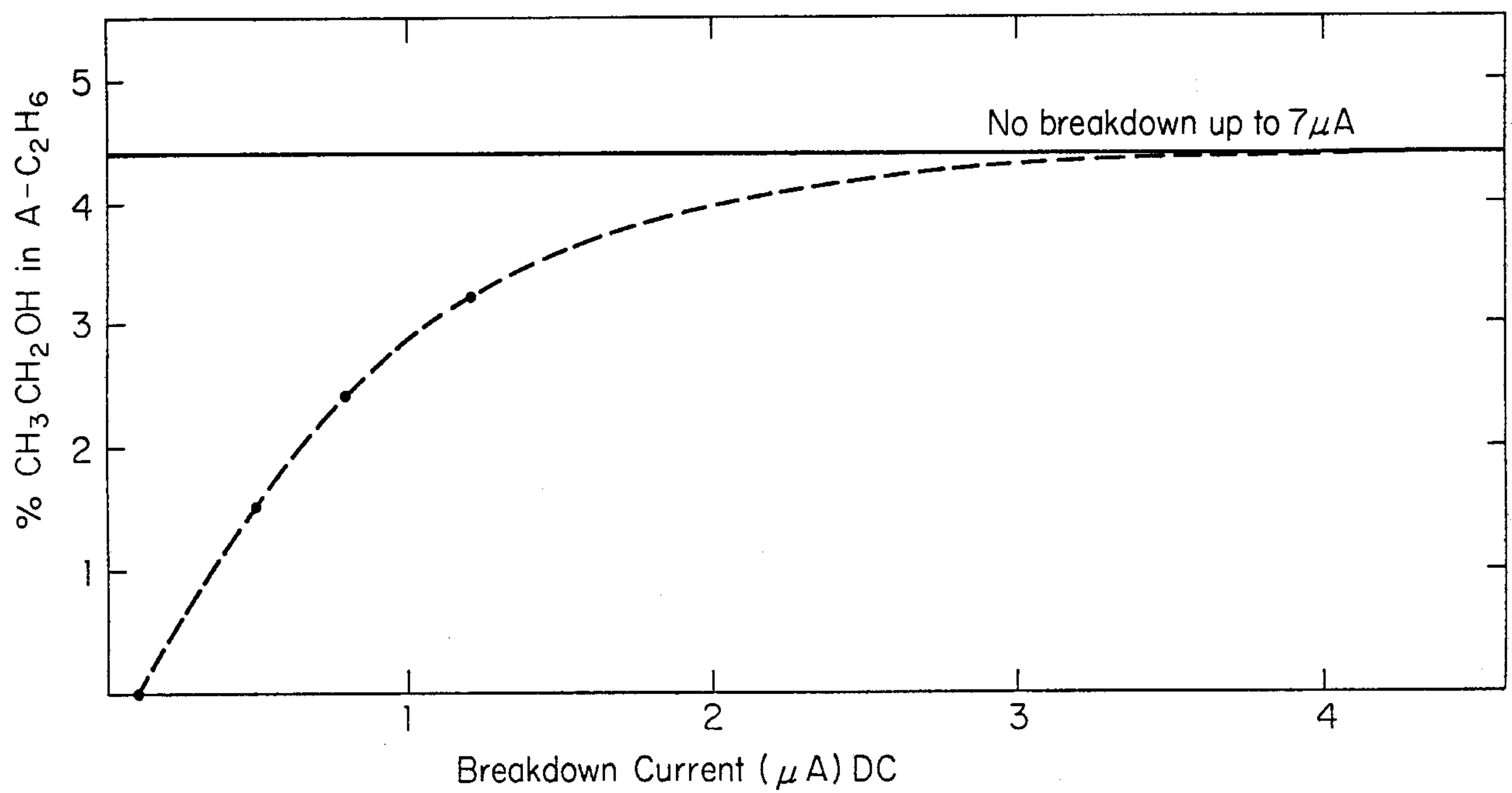
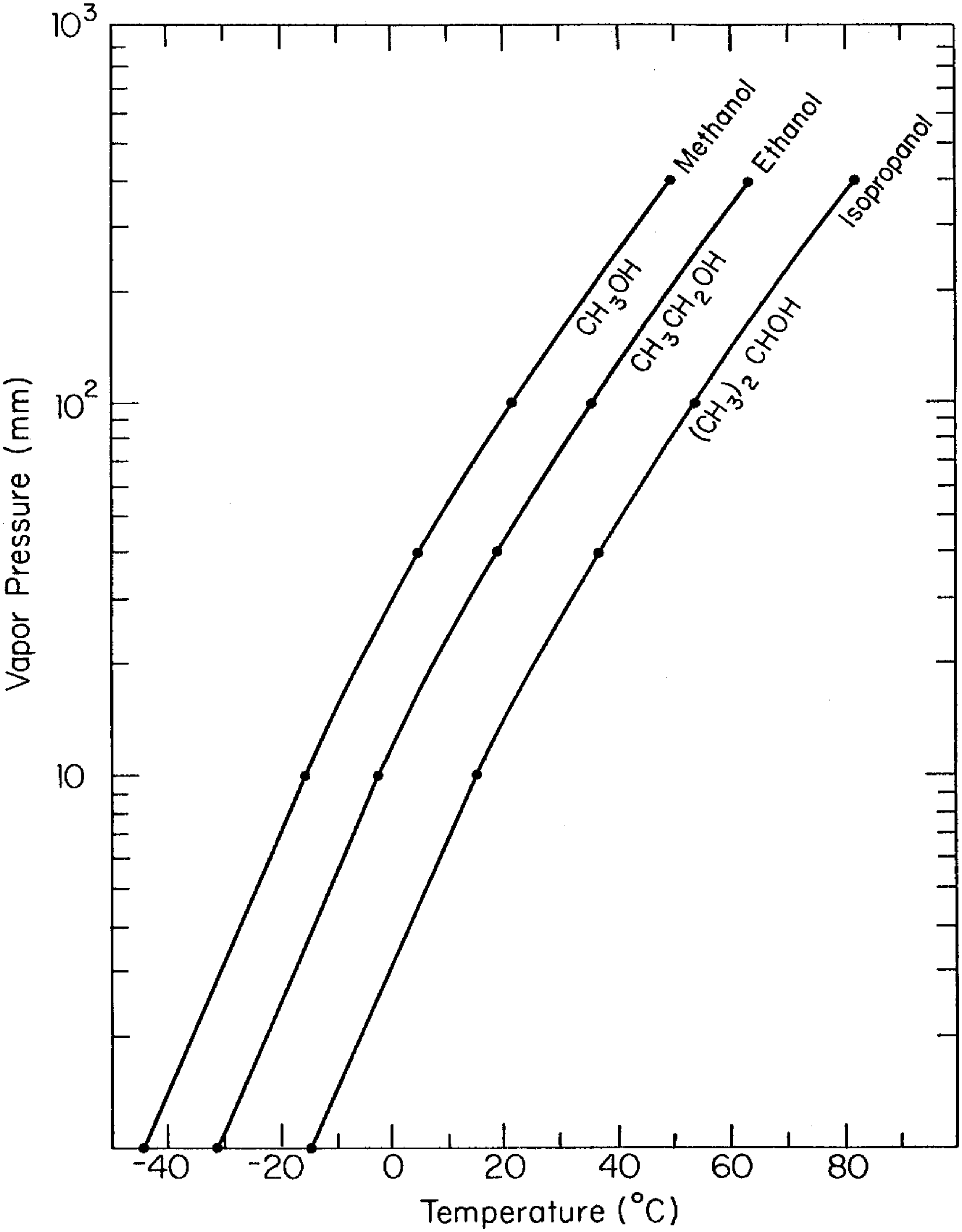

1
10^-1
10^-2
Power Supply Current (μA) DC
Breakdown
1.8
2.0
2.2
2.4
High Voltage (kV)

Fig. 7



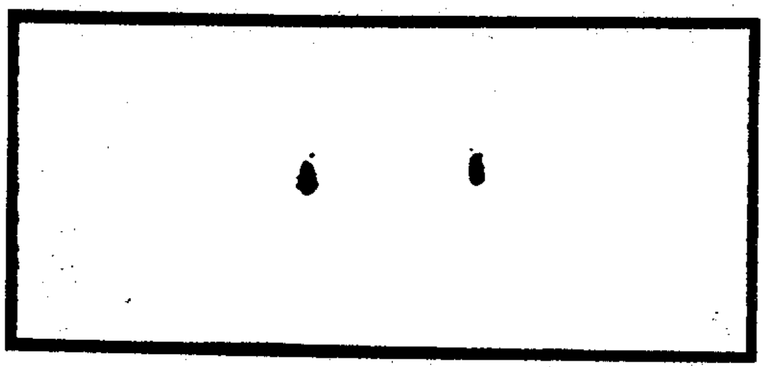
No breakdown up to 7μA
% CH3CH2OH in A-C2H6
5
4
3
2
1
1
2
3
4
Breakdown Current (μA) DC

Fig. 8

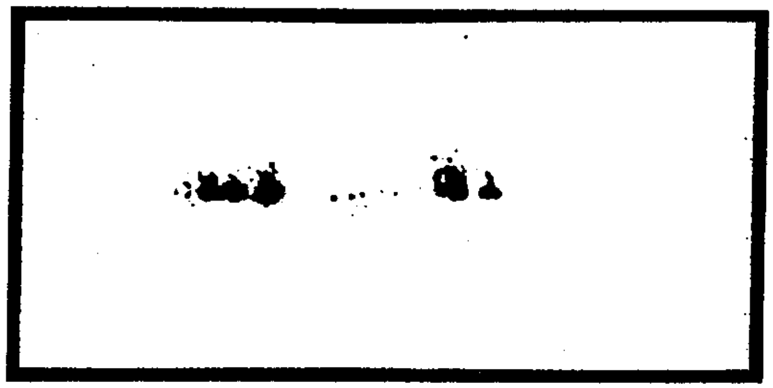


10^3
10^2
10
Vapor Pressure (mm)
Methanol
Ethanol
Isopropanol
CH3OH
CH3CH2OH
(CH3)2 CHOH
-40
-20
0
20
40
60
80
Temperature (°C)

Fig. 9



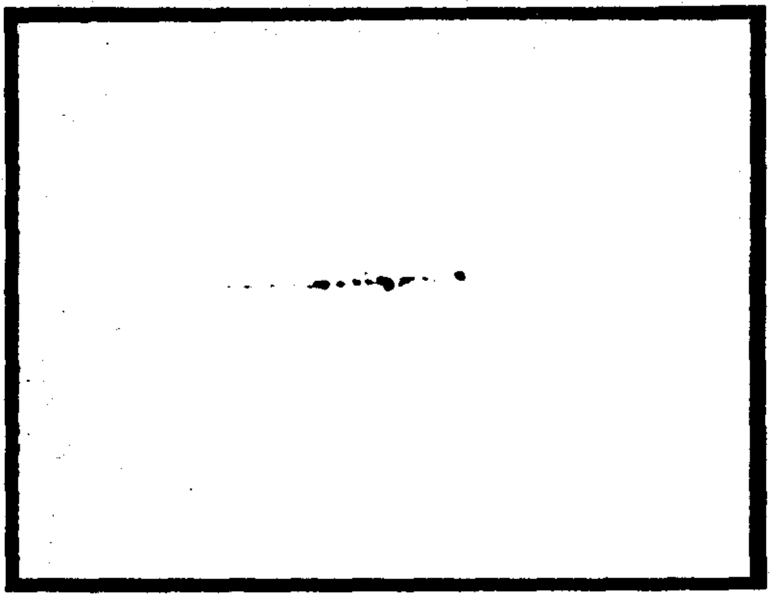
(a)



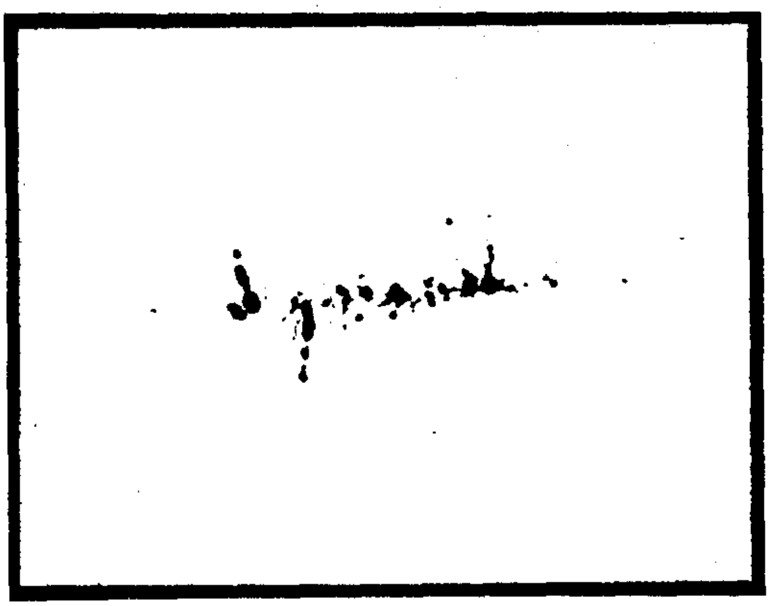
(b)

(c)

Fig. 10



(a)



(b)

Fig. 11

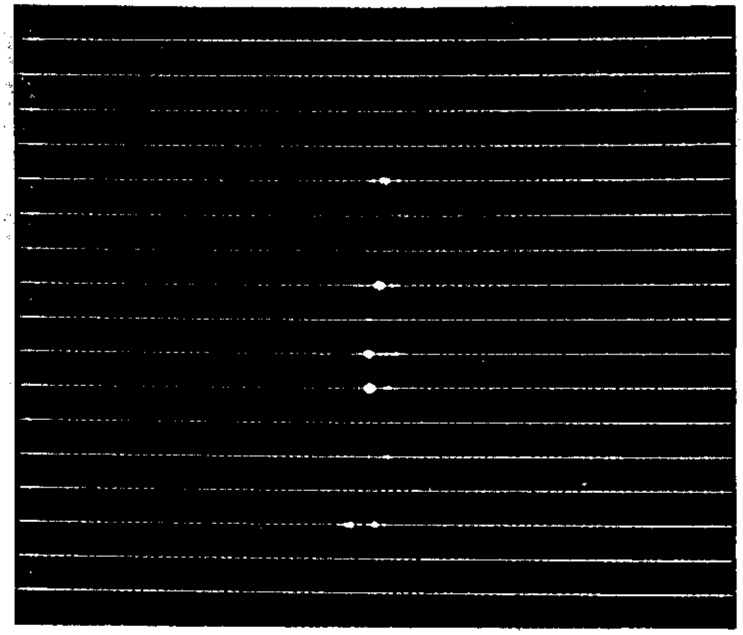


Fig. 12

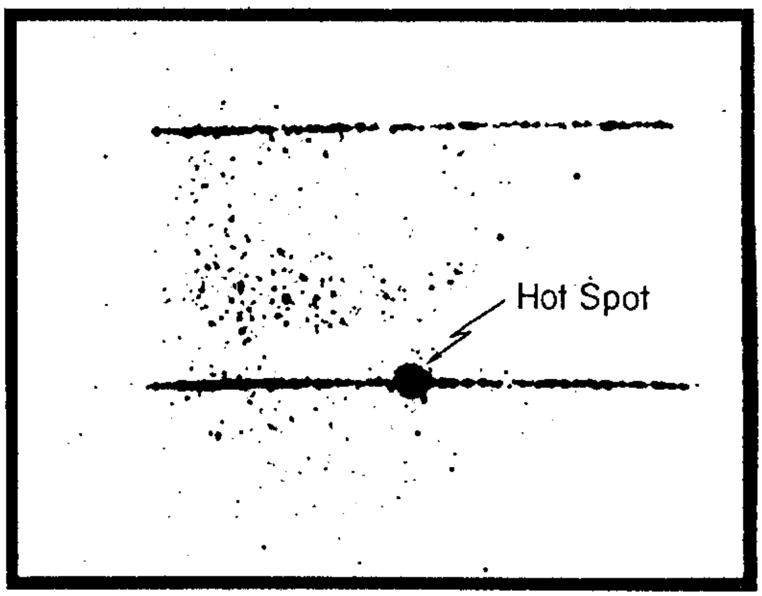
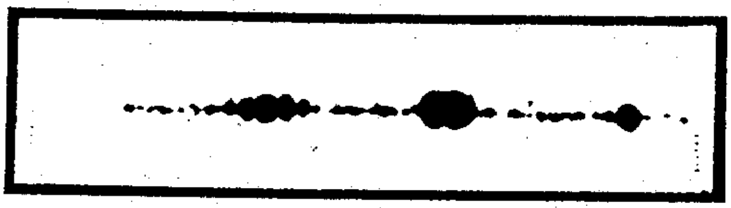
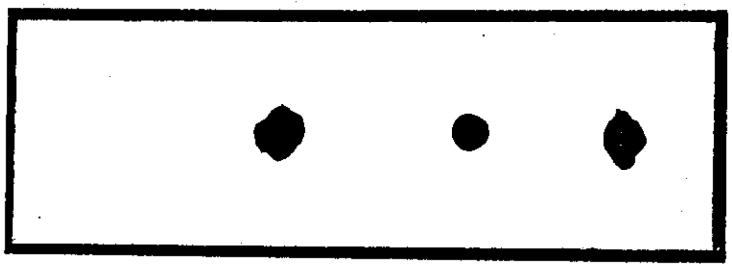


Fig. 13

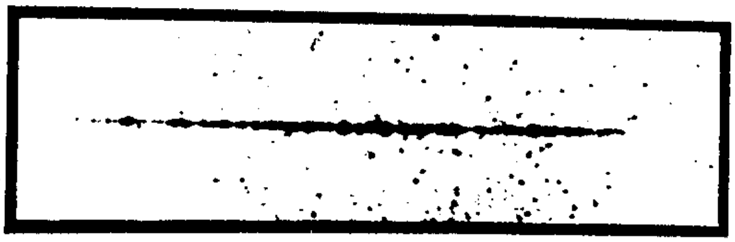


(a)



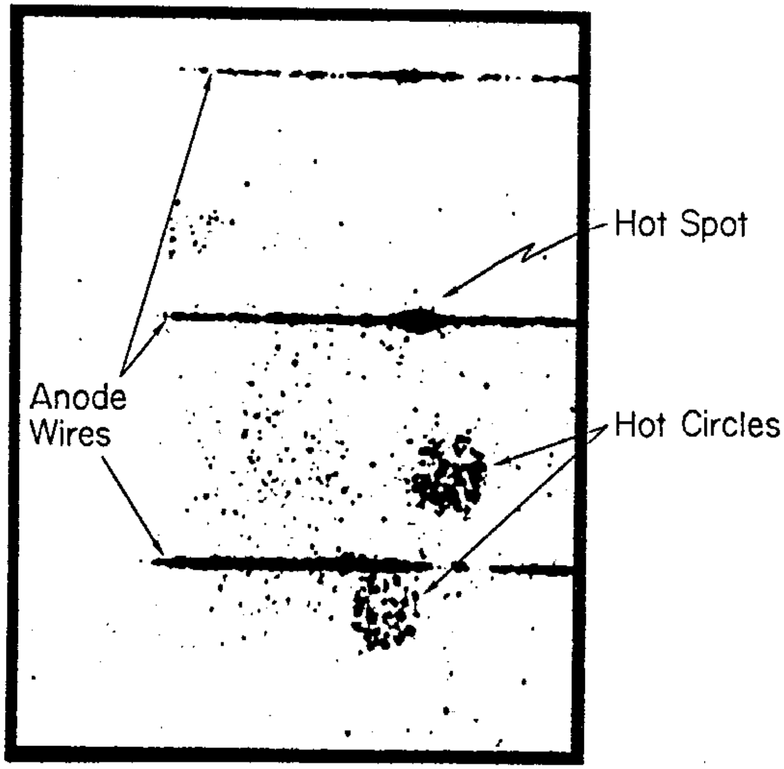
(b)

(c)

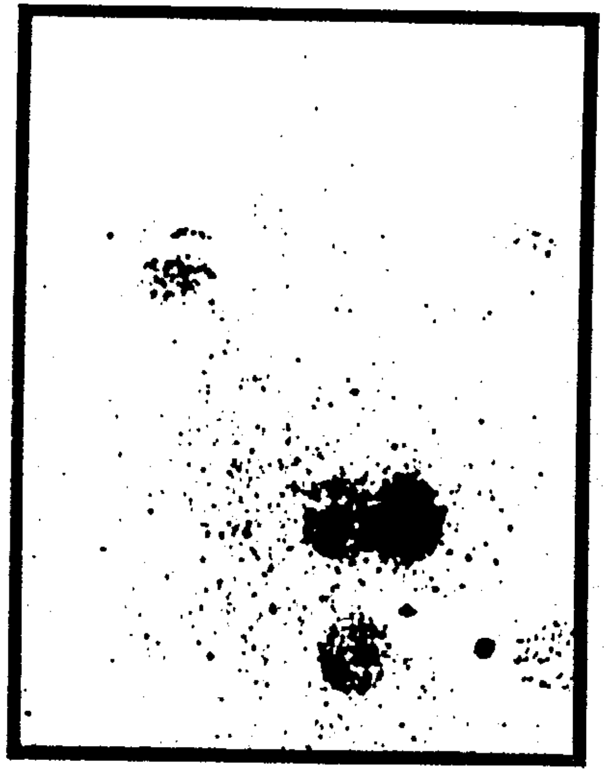


(d)

Fig. 14

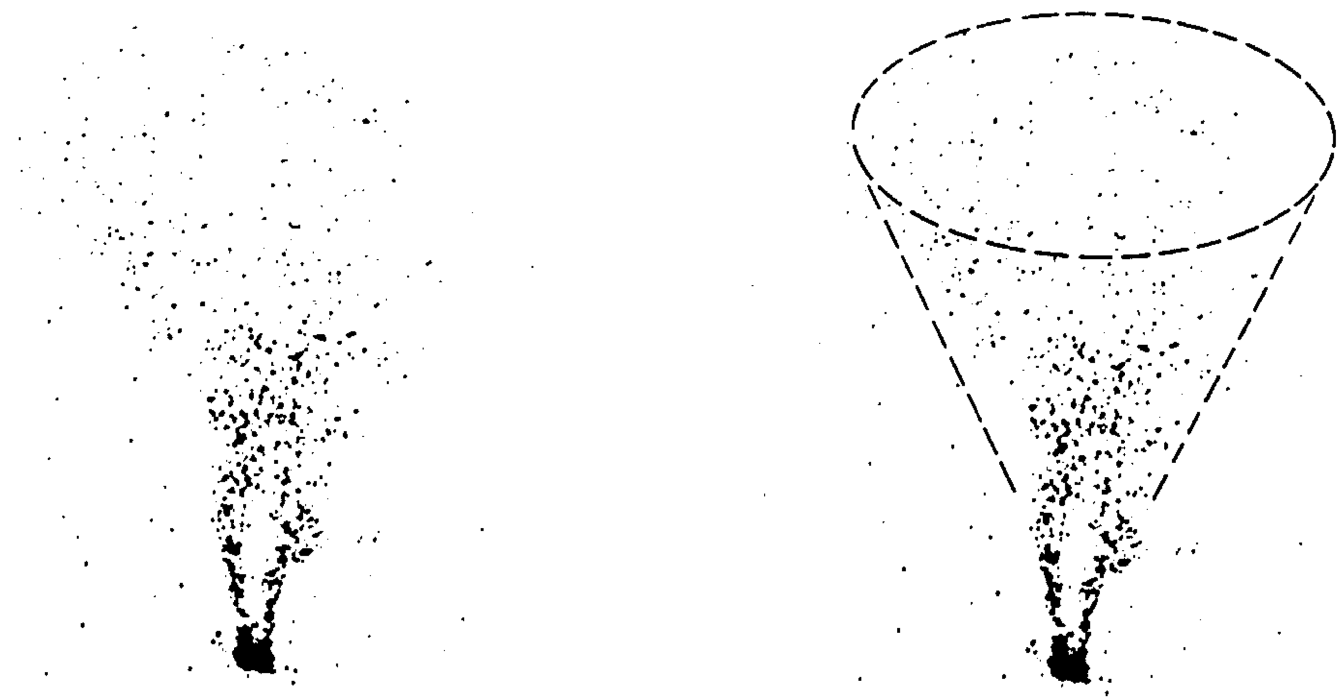


(a)



(b)

Fig. 15



(a) (b)

Fig. 16