High Voltage Engineering

Contents

ELRCTRIC BREAK DOWN IN GASES

- **Corona discharges.**
- **Break down in uniform fields.**
- **Break down under switching surge voltages.**

Corona discharge

a) Positive point corona
b) Negative point corona
c) Break down in non-uniform field gaps
d) Break down in switching surge voltage

Corona Discharge

- It is in fact break down of the air surrounding the high voltage conductor
- Corona includes transitory luminous and audible discharges in gaps at higher voltages conductor below the break down voltage
- The phenomenon is of particular importance in high voltage engineering where non-uniform fields are unavoidable

- Corona is responsible for considerable power losses from High voltage transmission lines and often leads to deterioration of insulating materials by the combined action of the discharge ions bombarding the surface and the action of chemical compounds that are formed by the discharges

Corona Discharge

- **Types of Corona**

1) **Audible Corona**
2) **Visible Corona**

- The voltage gradient at the surface of a conductor required to produce a visual a.c corona in air may approximately represents for the cases of coaxial cylinder and parallel wires arrangement respectively by the expression:

Voltage Gradient for Coaxial cylinder and parallel wires arrangement

$$E_e = 31me\left(1+\frac{0.308}{\sqrt{ea}}\right)(peak\ kV/cm)$$

and

$$E_w = 30me\left(1+\frac{0.301}{\sqrt{ea}}\right)(peak\ kV/cm)$$

Where

a= radius of wire in cm
m= surface irregularity factor
=1 for smooth polished surface
e= Relative air density factor
= 3.92b/ (273+t)
b= barometric pressure in cm Hg
t= temperature in ^{o}C
e=1 at 76 cm-Hg and 25^{o}C

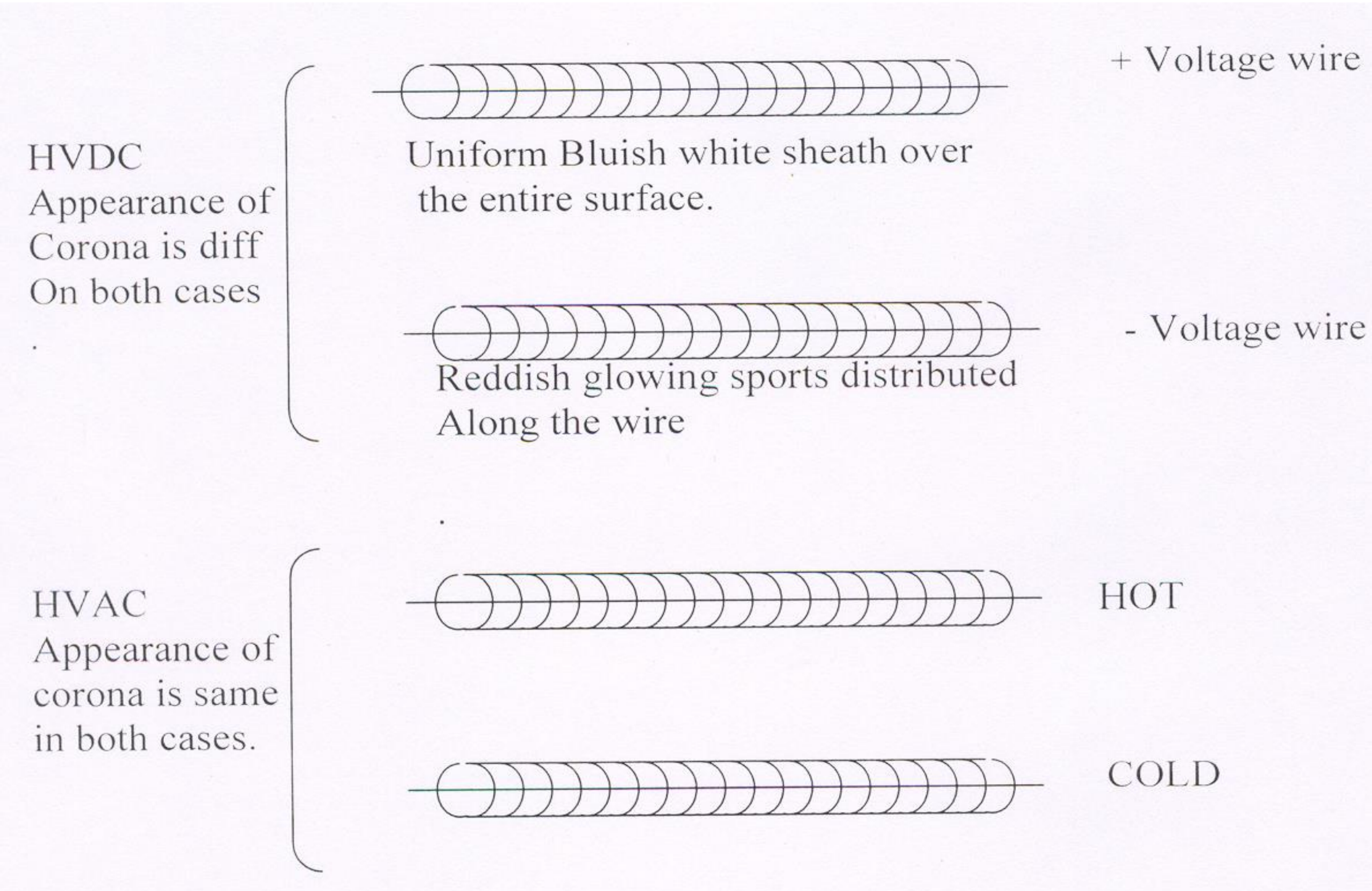
- These expressions are found to hold down to a pressure of quite high value

- On high voltage wires at high pressure there is a distinct difference in visual appearance of corona under the two polarities.

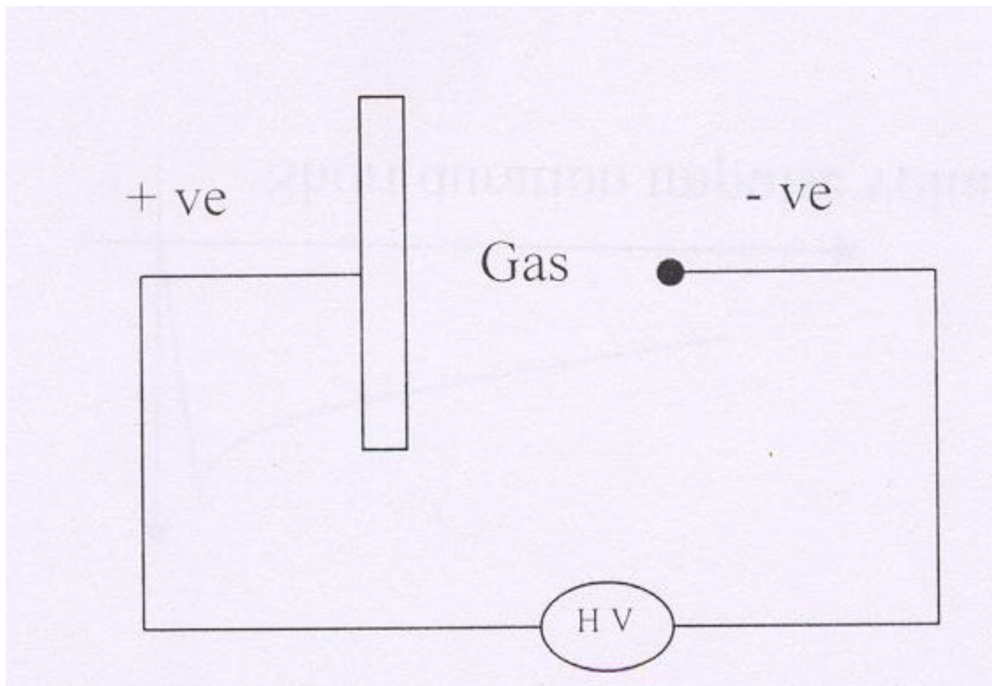
- Corona on AC and DC overhead transmission lines is due to ionization of the air surrounding the conductor.
- But the direction of the movement of charged particles around the conductor in AC and DC is different.
- In case of DC, the corona phenomenon is related with field distribution rather than surface stress
- Therefore, the importance for the consideration of the corona phenomenon while designing HVDC lines is less serious than while designing AC lines
- In addition, corona loss is less due to the absence of factor in HVDC voltage waveform.

- Corona losses on DC lines is an important factor and should be considered while calculating the line losses for designing the HVDC lines
- Losses in HVDC monopolar lines are less when compared to those in HVDC bipolar lines.

Corona Appearance in different cases



NEGATIVE POINT-PLANE CORONA



With negative point the corona current flows in very regular pulses whose repetition frequency increases with the current

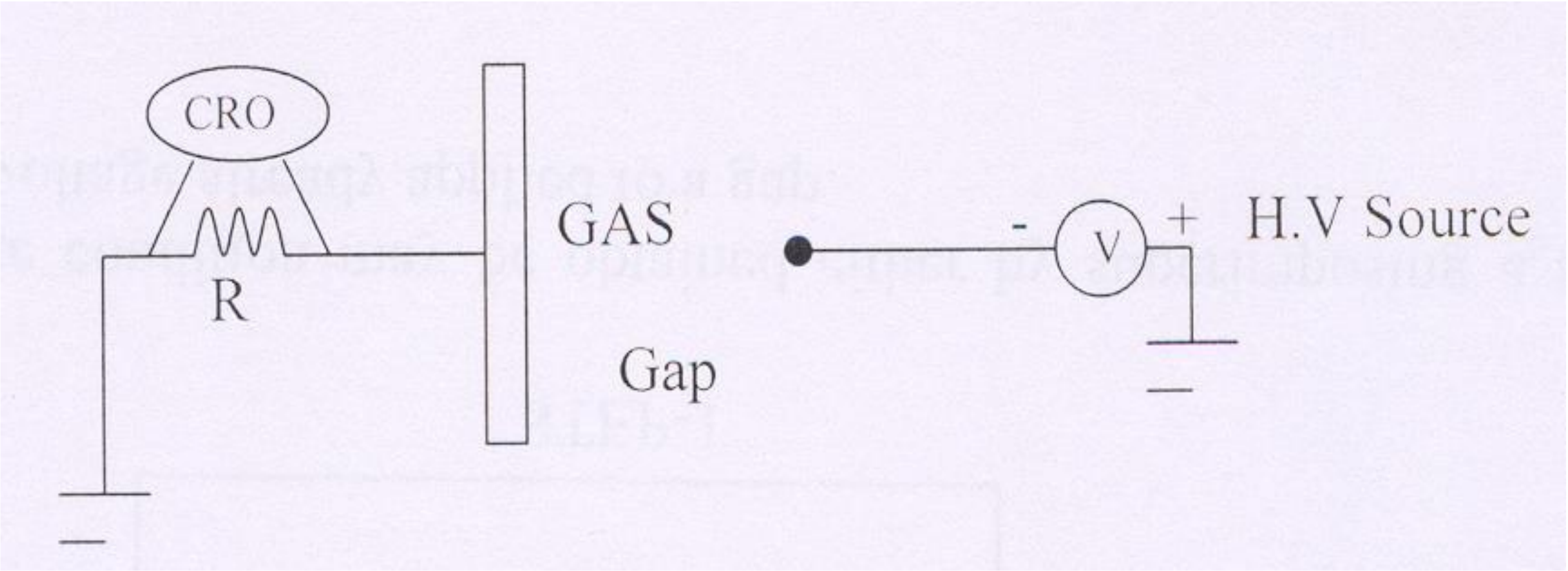
The frequency is largely independent of the gap length but it increases with the point sharpness

TRICHEL’S Pulses

The first systematic study of negative corona was made by Trichel and the pulses have been named after their discoverer as Trichel’s pulses

The apparatus required for studying corona consists simply of Point-Plane gap with the point connect to the high voltage source.

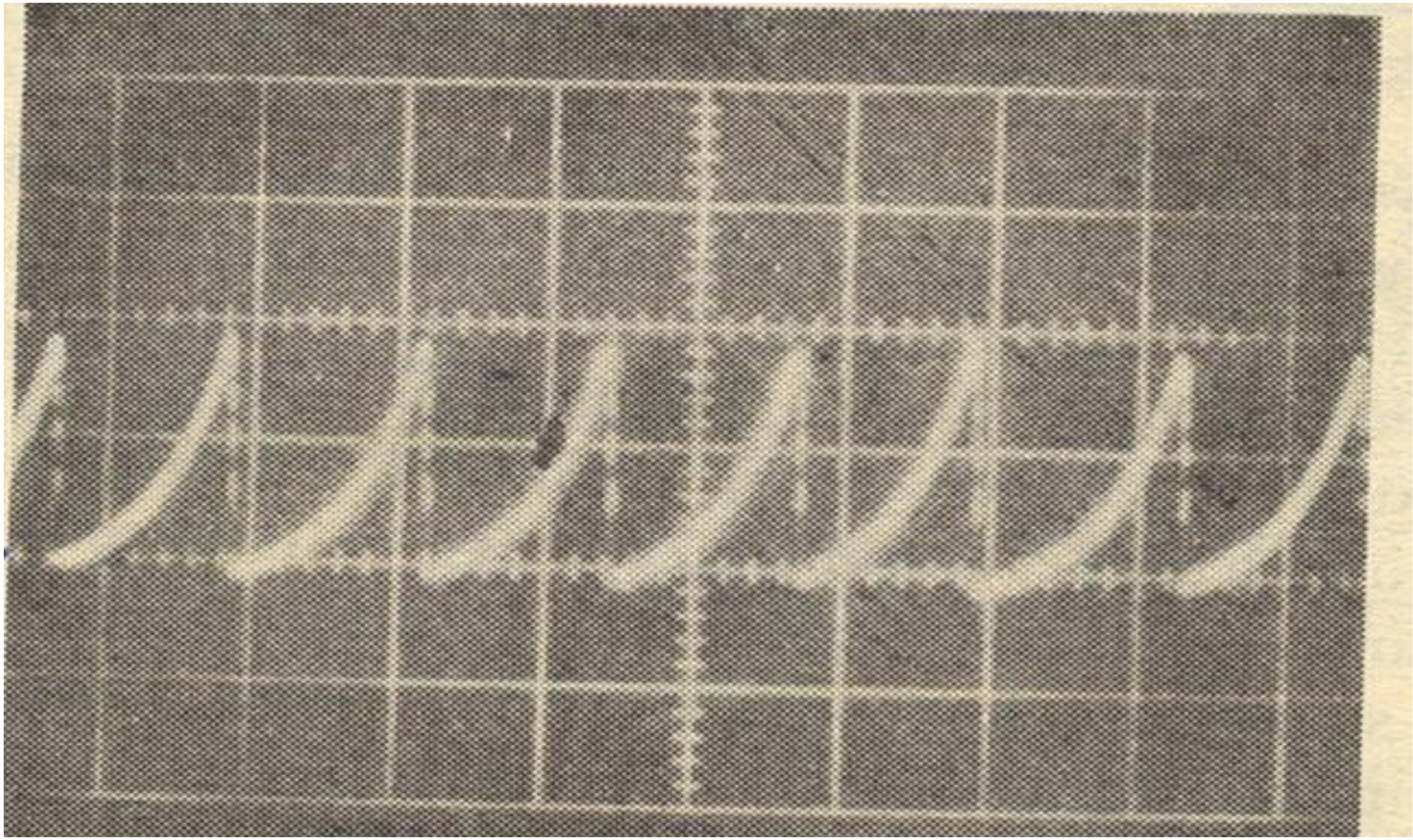
Trichel Pulses



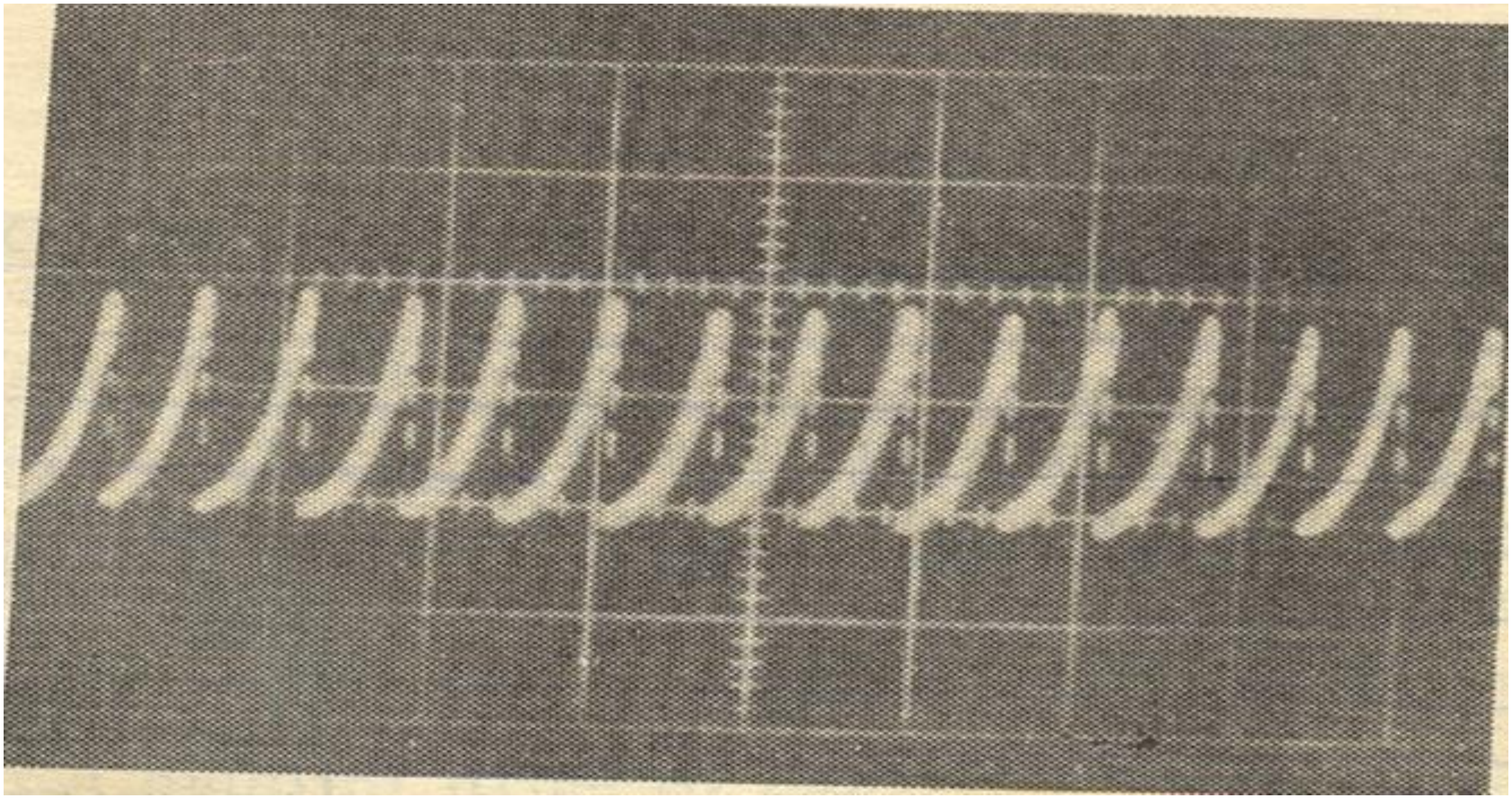
TRICHEL'S Pulses

- The plate is connected to earth through a resistance and the voltage drop across the resistance is displayed on a Cathode-Ray Oscilloscope (CRO) of suitable sensitivity
- The pattern of succession of Trichel's pulses at pressure of 100mmHg for 1mm diameter point and 4cm gap at 2.0 and 2.2 KV is shown in **fig . (a)** and (b)

Current with 2.0 kV , Fig (a)

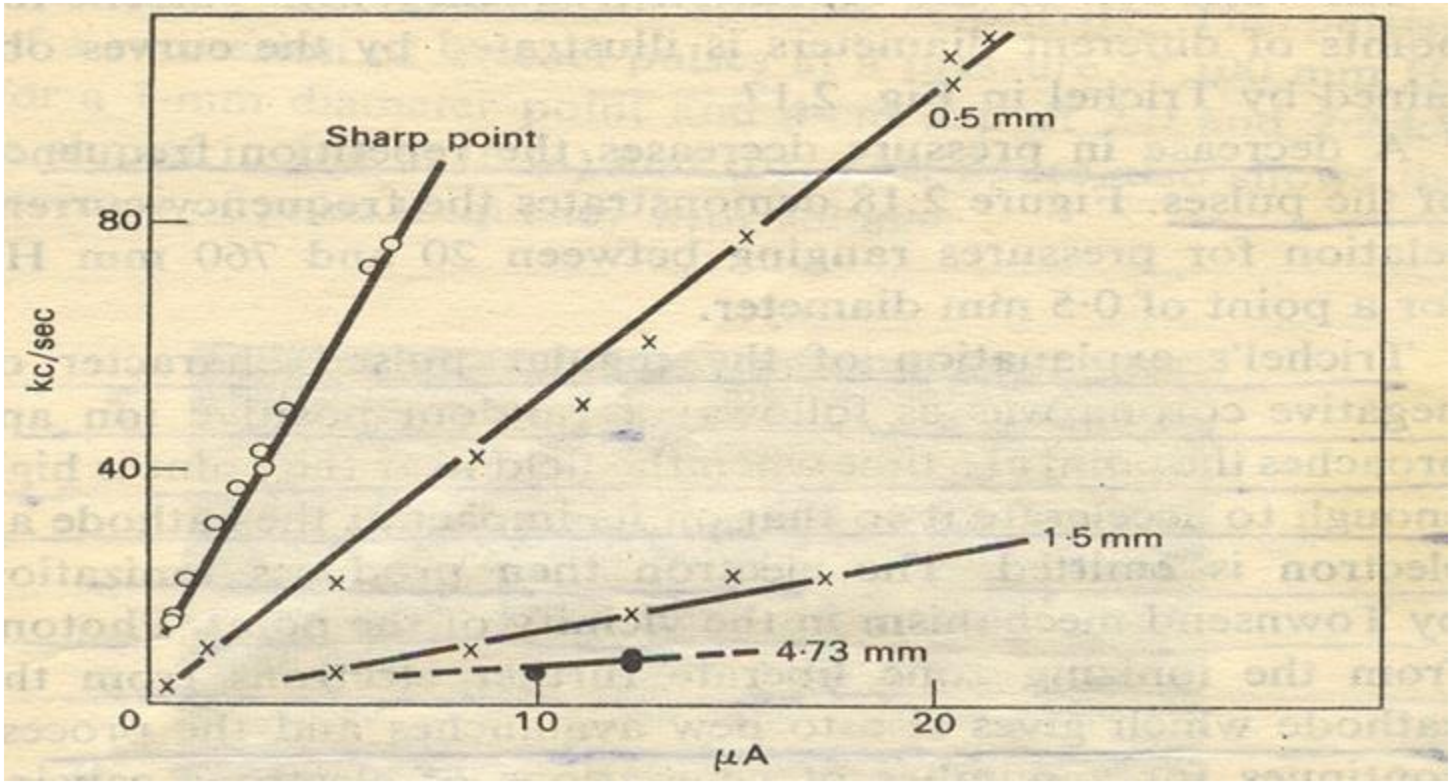


Current with 2.2 kV , fig (b)



TRICHEL'S Pulses

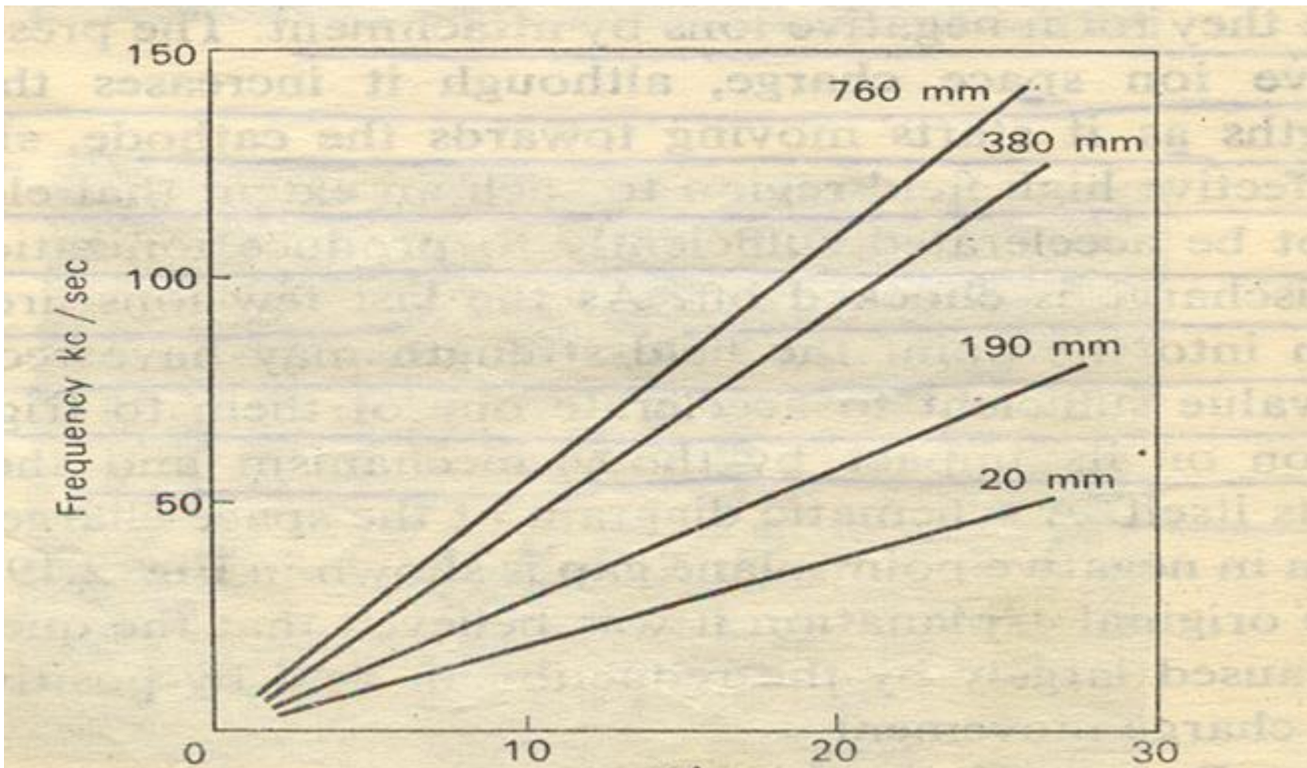
The variation of the frequency with the current for point of different diameters is illustrated by curves obtained by Trichel in **fig in subsequent slide**



Sharp point
0·5 mm
1·5 mm
4·73 mm
80
40
0
10
20
kc/sec
μA

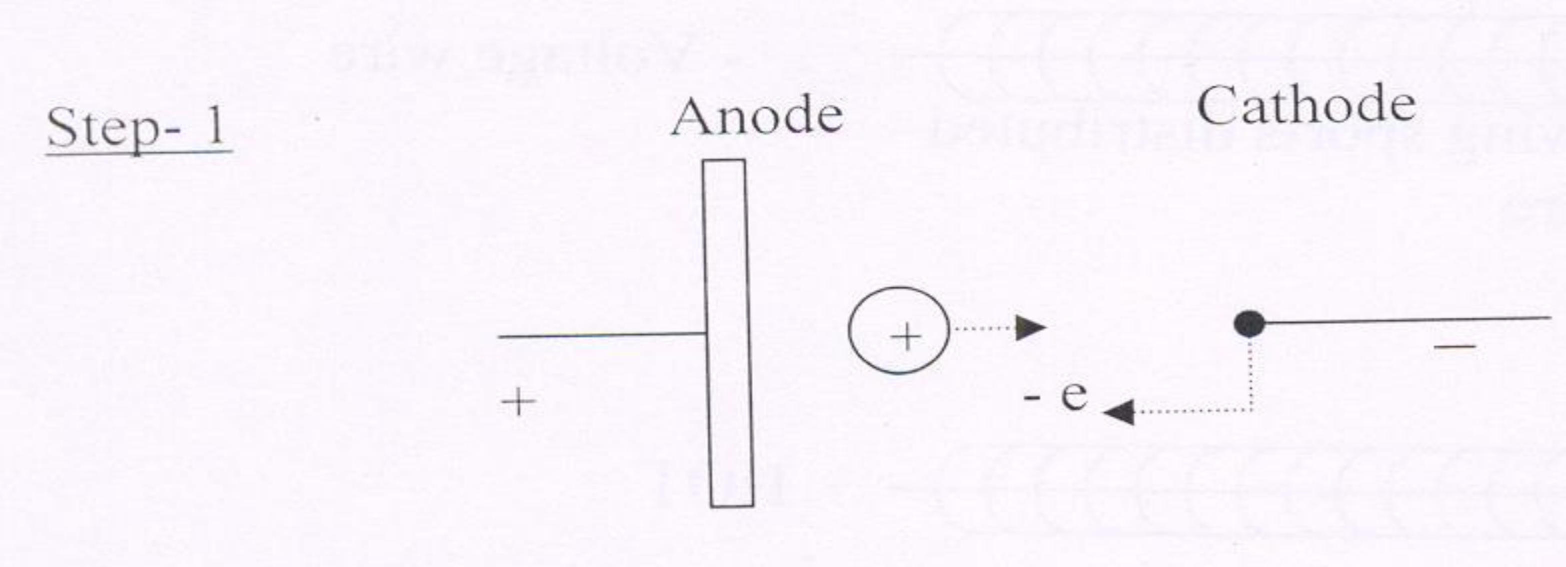
- A decrease in pressure decreases the repetition frequency of the pulses
- **Fig in next slide** demonstrates the frequency –current relation for pressures ranging between 20 and 760mmHg for a point of 0.5mm diameter

Pulse frequency variation with Corona current with different pressure



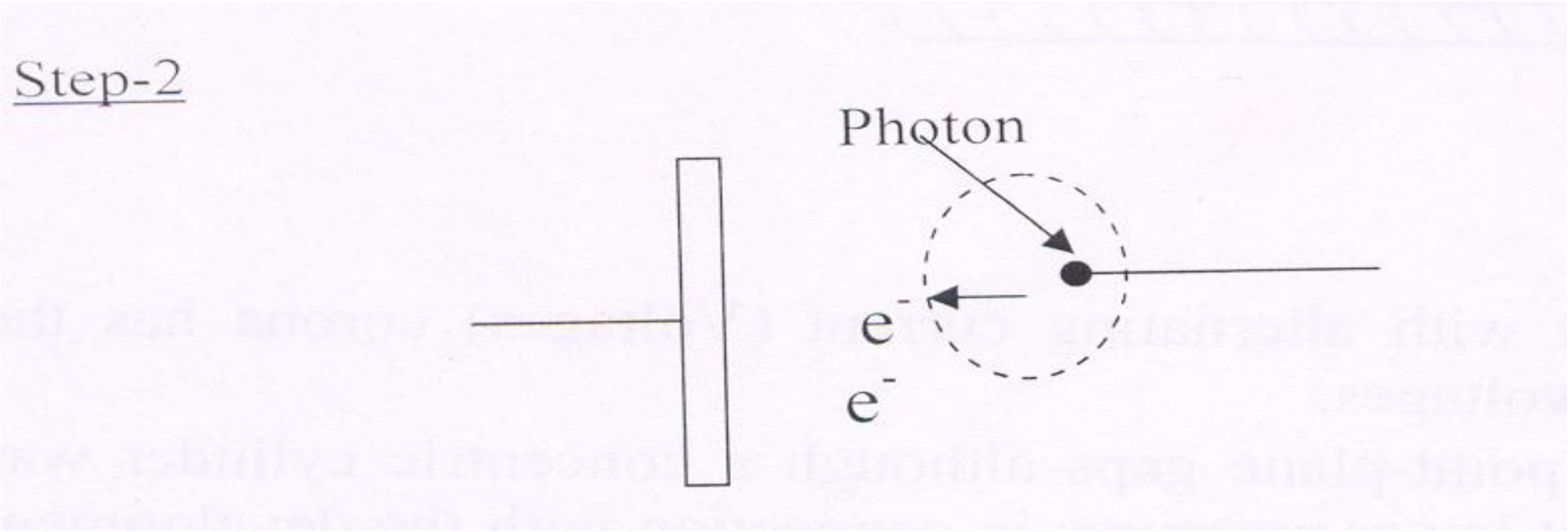
TRICHEL'S Pulses

Trichel's explanation of the regular pulsed character of negative corona was as follows



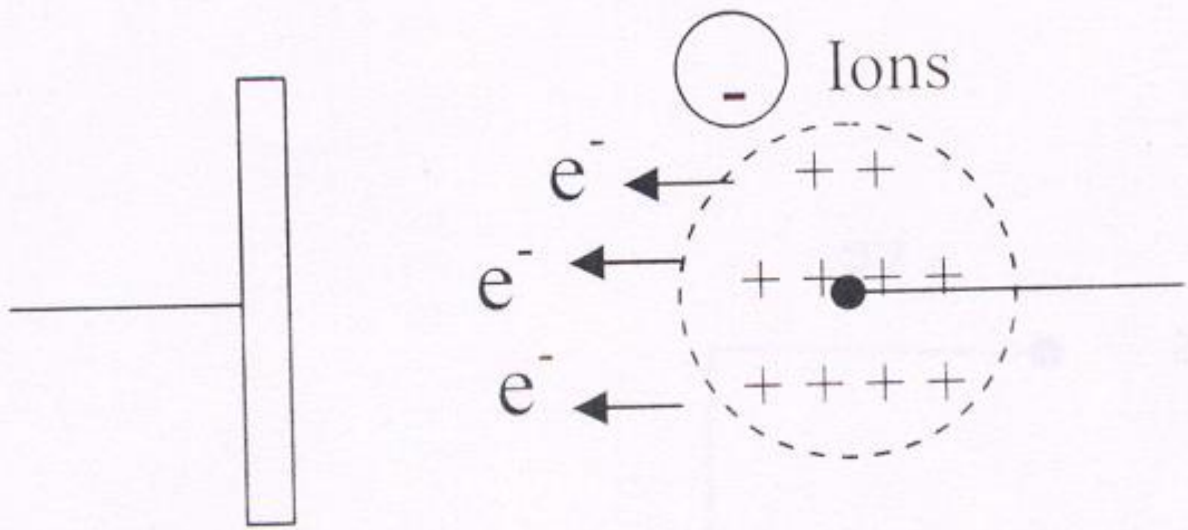
TRICHEL'S Pulses

Random positive ion approaches the point at a time when the field near the point is high enough to accelerate it so that on its impact at cathode an electron is emitted.



- The electron then produces ionization by Townsend mechanism in the vicinity of point
- Photons from the ionizing zone liberate further electrons from the cathode which gives rise to new avalanche and the process continue for a number of generations of electrons causing a rapid rise in current

Step-3

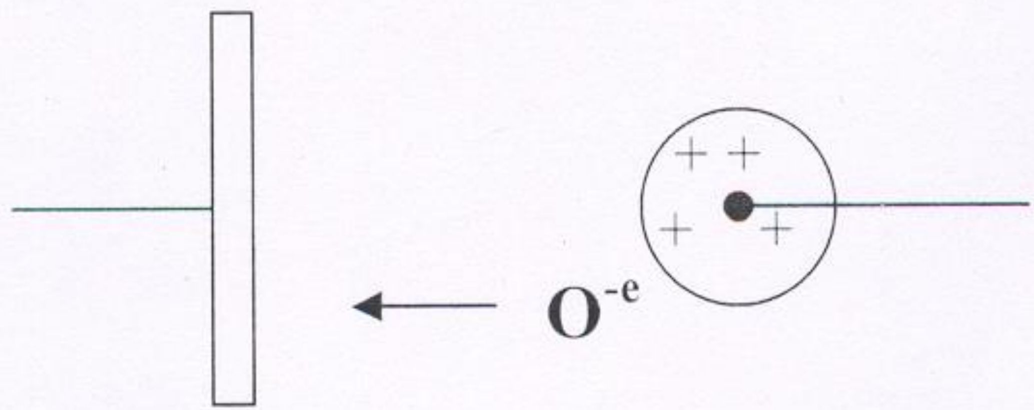


TRICHEL'S Pulses

A dense cloud of positive ion is formed near the point with the electrons moving away into the gap where they form negative ions by attachment

The presence of positive ion space charge, although it increases the field strengths as it starts moving towards the cathode, shortens the effective high field region to such an extent that electrons can not be accelerated sufficient to produce ionization and the discharge is chocked off

Step-4



TRICHEL'S Pulses

As the last few ions are being driven in to point the field strength may have recovered to a value sufficient to accelerate one of them to trigger an electron on its impact by the γ_i mechanism and the cycle repeats itself.

- A schematic diagram of the space charge distribution in negative point plane gap is shown in **fig in next slide**

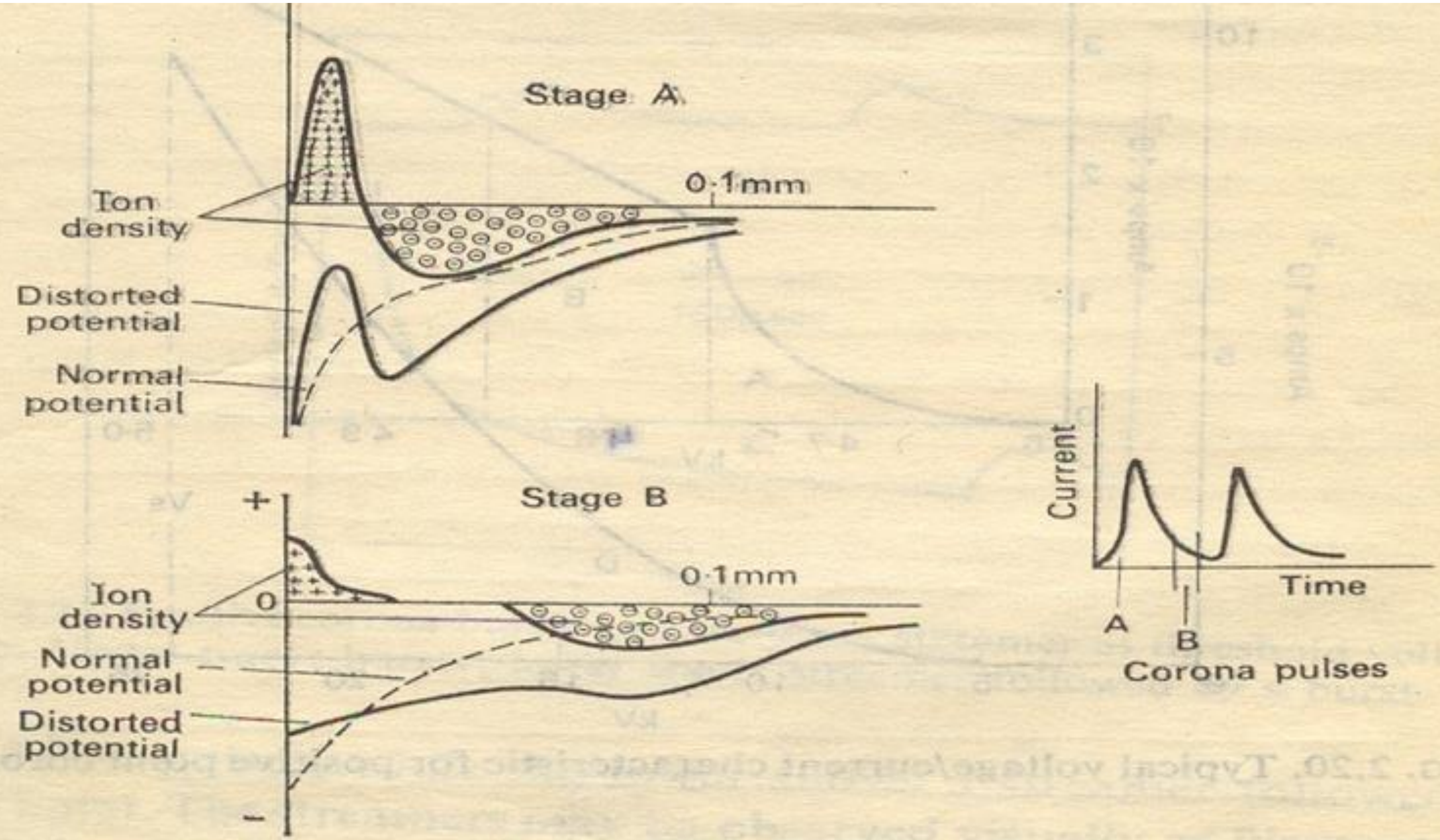
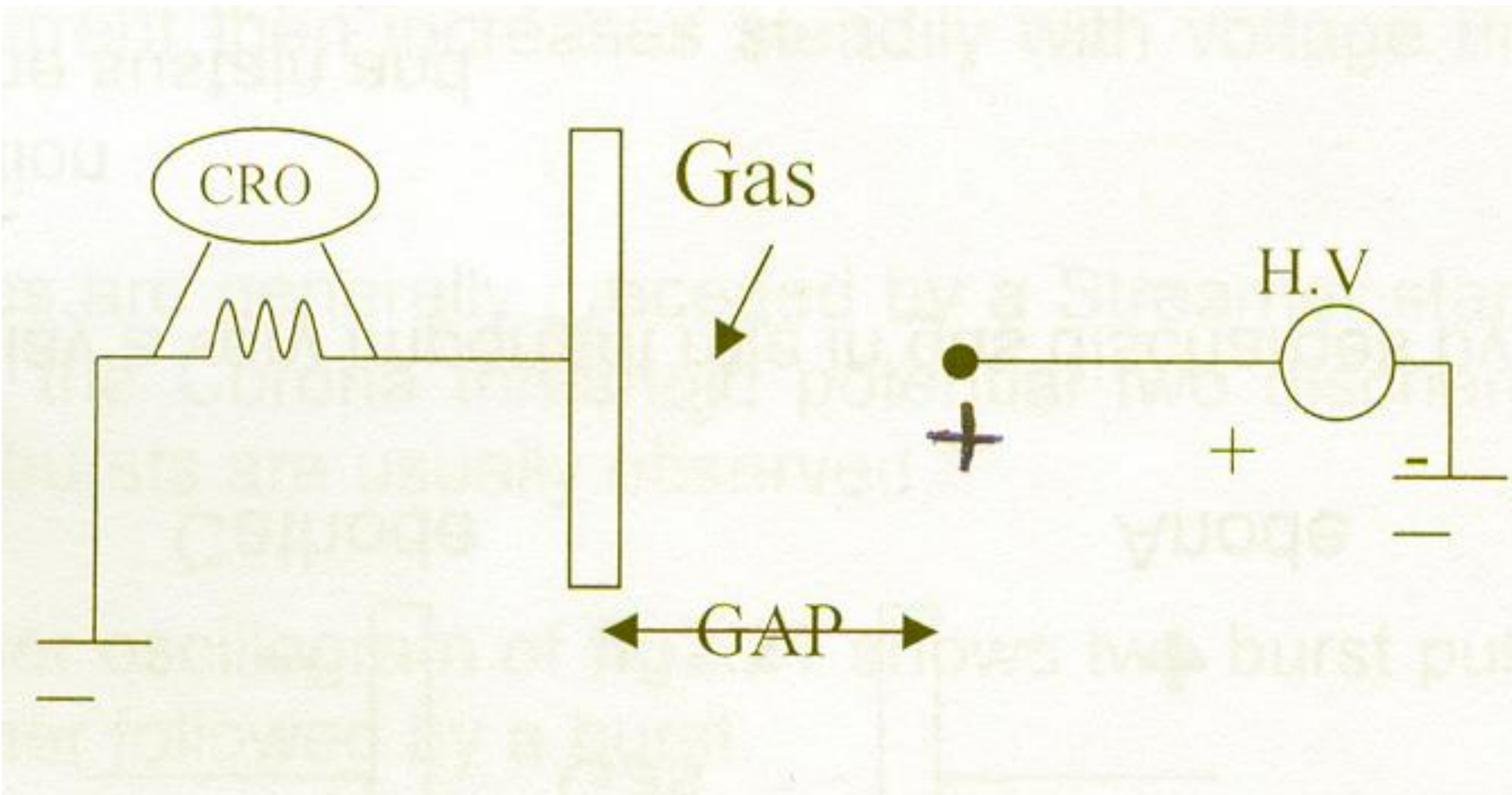


FIG. Schematic diagram of space charge distribution in negative point corona.

TRICHEL'S Pulses

Thus in the organized explanation it was believed that the quenching was caused largely by the reduction in field by positive ion space charge movement


CRO
Gas
H.V
+
+
-
GAP

POSITIVE POINT CORONA

With positive point in air corona current increases steadily with voltage as is shown in **fig**

At sufficiently high voltage electrons produced near the point by external agencies form avalanches directed towards the point (Region “A” **fig).**

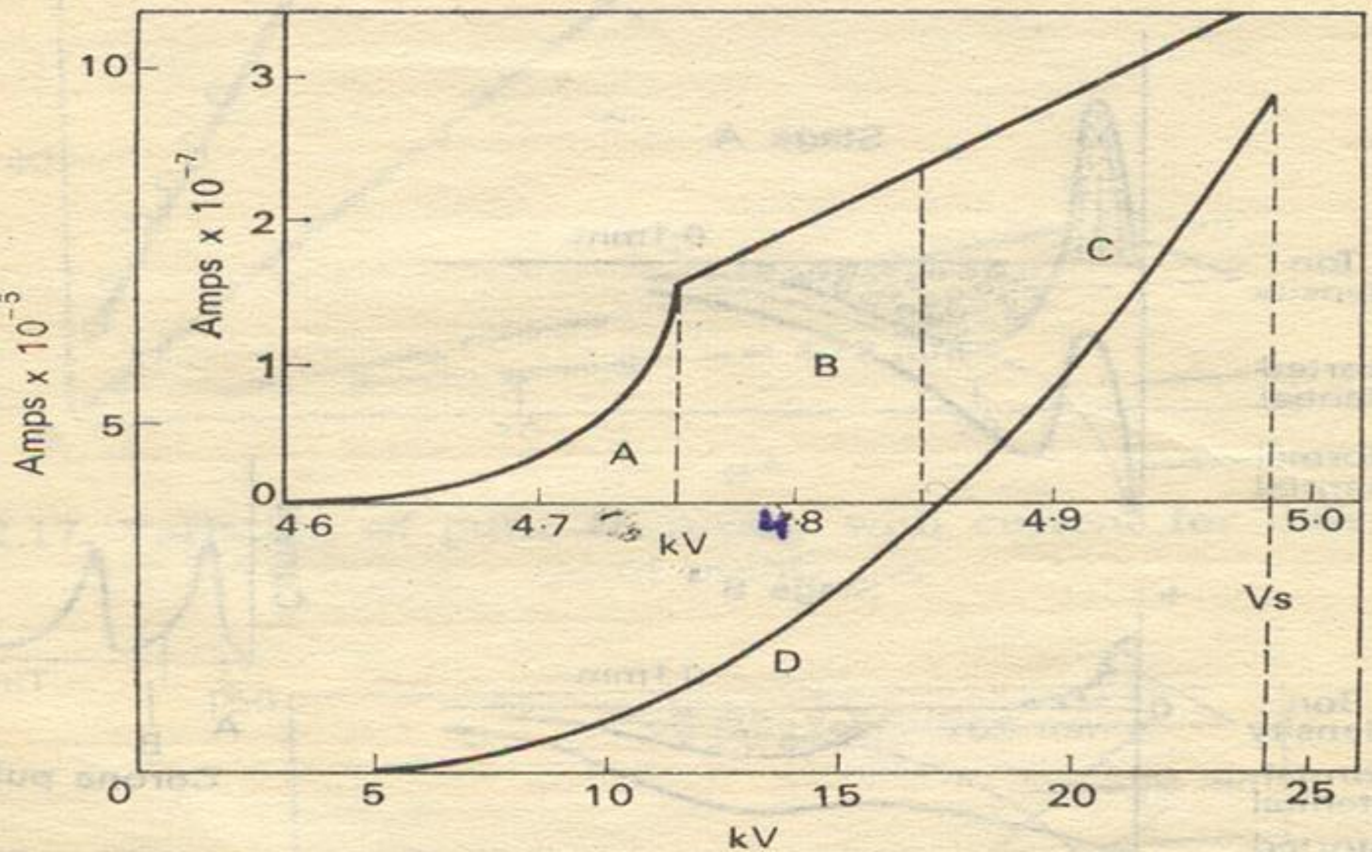


FIG. Typical voltage/current characteristic for positive point corona.

POSITIVE POINT CORONA

These give current amplification increasing rapidly with voltage up to values of the order 10^{-7} A, after which the current suddenly increases in the form of pulses of current with repetition frequency ≈ 1Kc/sec composed of small bursts (region B), called this corona as “Burst Corona”

The average current then increases steadily with voltage until the discharge becomes self-sustained.

POSITIVE POINT CORONA

The Burst pulses generally come fisrt by a Streamer starting from the point towards the plate

Near the Corona threshold potential two discharge forms corresponding to Streamers and bursts are usually observed

The upper oscillogram of **fig in next slide** shows two burst pulses, while the lower shows a streamer followed by a burst.

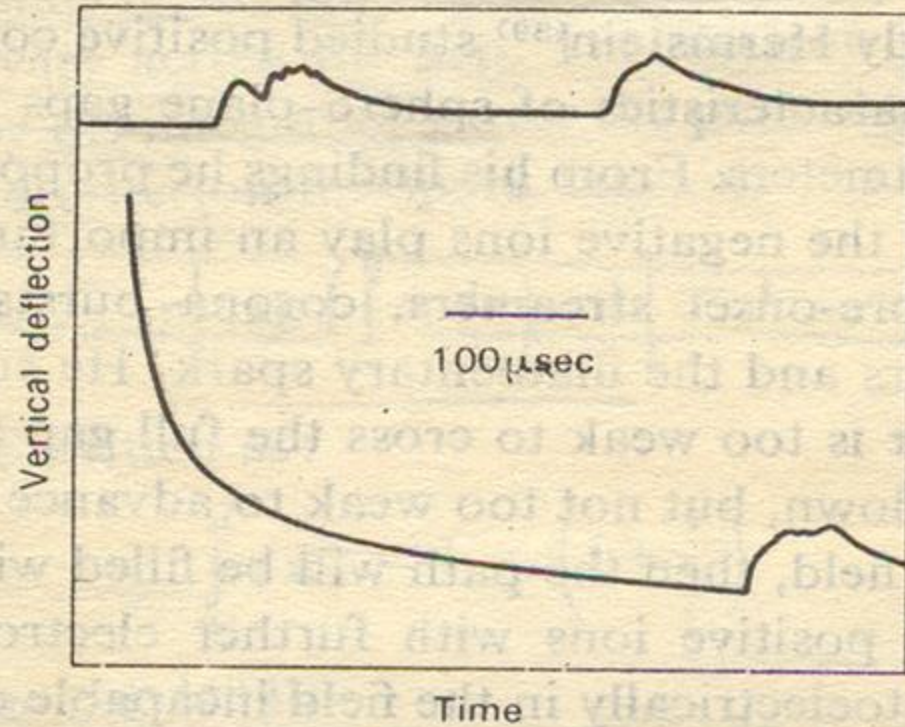


FIG. Positive corona bursts and pre-onset streamer at threshold voltage. Upper trace: bursts; lower trace: streamer followed by a burst.

POSITIVE POINT CORONA

As the voltage is increased the streamer becomes longer and more energetic and the burst pulses increases in duration (region C)

At still higher voltages the streamer ceases with start of steady burst corona. (Region D)

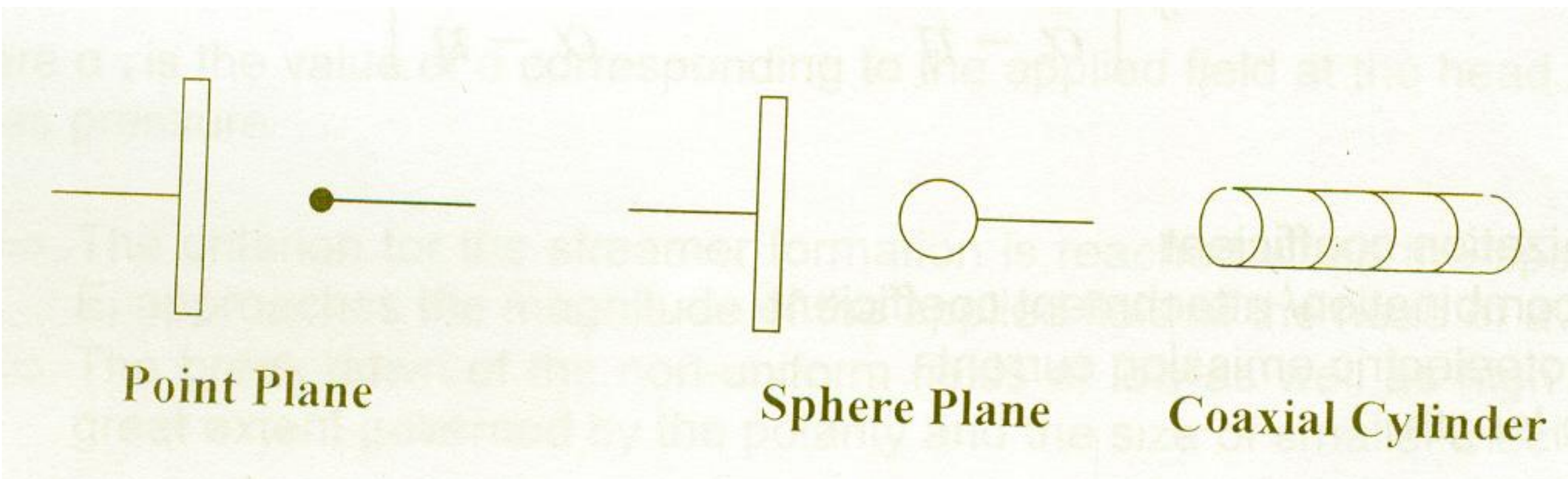
Kip’s Theory

Kip suggested that once the streamer has propagated its own space charge slows down further streamer growth

Thus following Streamer’s there are smaller pulses of longer duration

Streamers were suggested to trigger burst pulses but burst could also start on their own accord if there is sufficient space charge present in the gap

Breakdown in Non Uniform fields



In non-uniform fields, e.g. in point plane, sphere plane gaps or co-axial cylinders, the applied field and the 1st Townsend's coefficient "α" vary across the gap

The electron multiplication is governed by the integral of "α" over the path

At low pressures the Townsend's criterion for sparks takes the form:

$$\gamma \, [\, e^{\alpha d} - 1] = 1$$

$$\gamma\left[\exp\left(\int_{o}^{d}\alpha\ dx\right)-1\right]=1$$

Which can be written as :

$$\int_{o}^{d}\alpha\ dx=\log_{e}\left(1+\frac{1}{\gamma}\right)$$

Where d=gap length

- For the case of co-axial cylinders the integration limits become the radii of the inner and the outer cylinder
- Meek and Raether also discussed the break down in non-uniform field in the frame of streamer theory
- In this case the expression for the space charge field E_r at the head of avalanche, when it has crossed the distance x in non-uniform field is given by:

$$E_r = \frac{5.27\times10^{-7}\alpha_x \exp\left(\int_0^d \alpha\, dx\right)}{\sqrt{\left(\frac{x}{p}\right)}} \quad v/cm$$

Where α_x is the value of α corresponding to the applied field at the head of avalanche

P=gas pressure

The criterion for the streamer formation is reached when the space-charge field E_r approaches the magnitude of the applied field at the head of avalanche

The break down of the non-uniform fields at low as well as high pressures is to great extent governed by the polarity and the size of smaller electrode

At the low pressures the break down is generally lower when the smaller electrode is negative

This is also true for non-attaching gases at high pressures.

Fig in next slide shows the direct voltage break down characteristics for nitrogen at low pressures between a wire and co-axial cylinder.

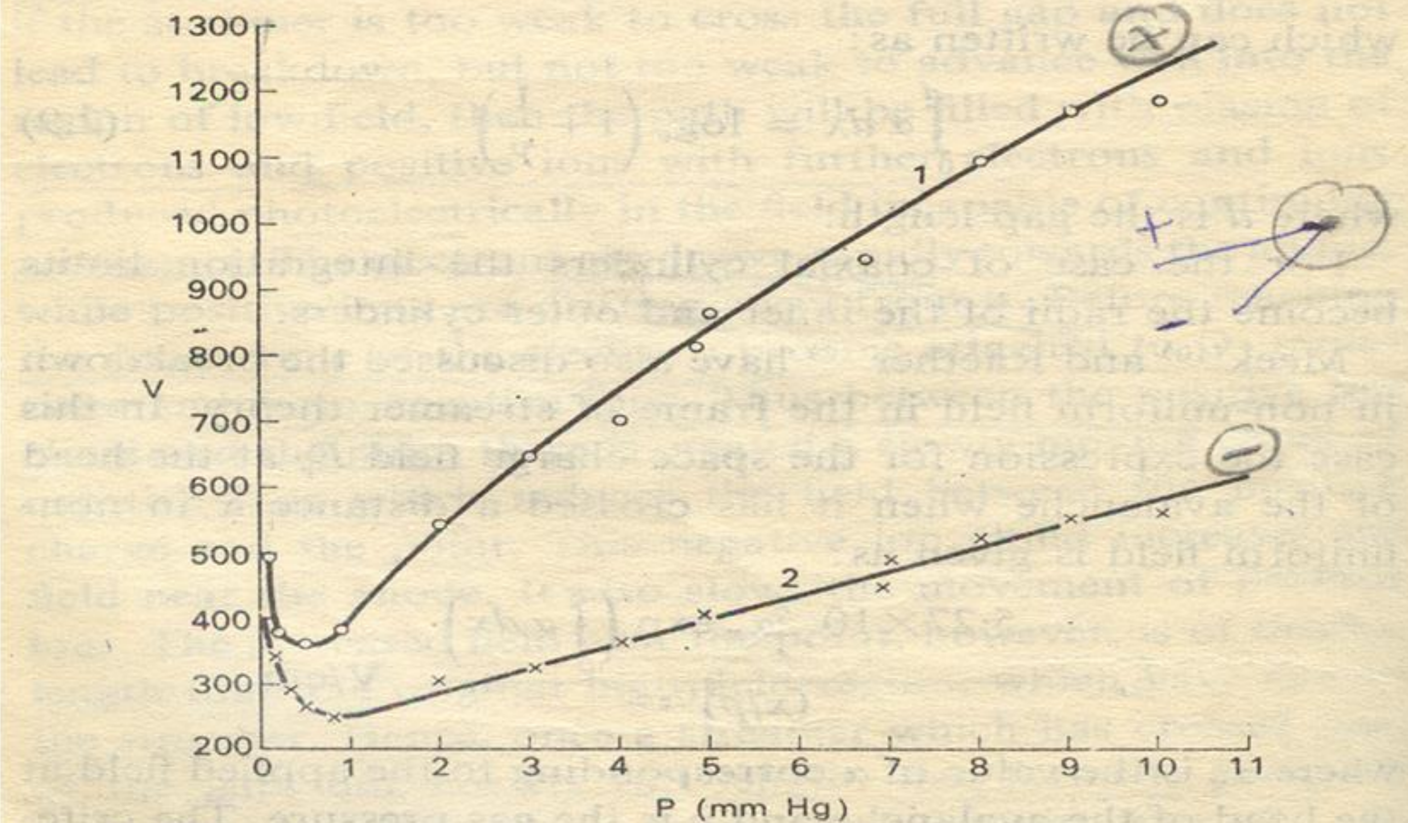
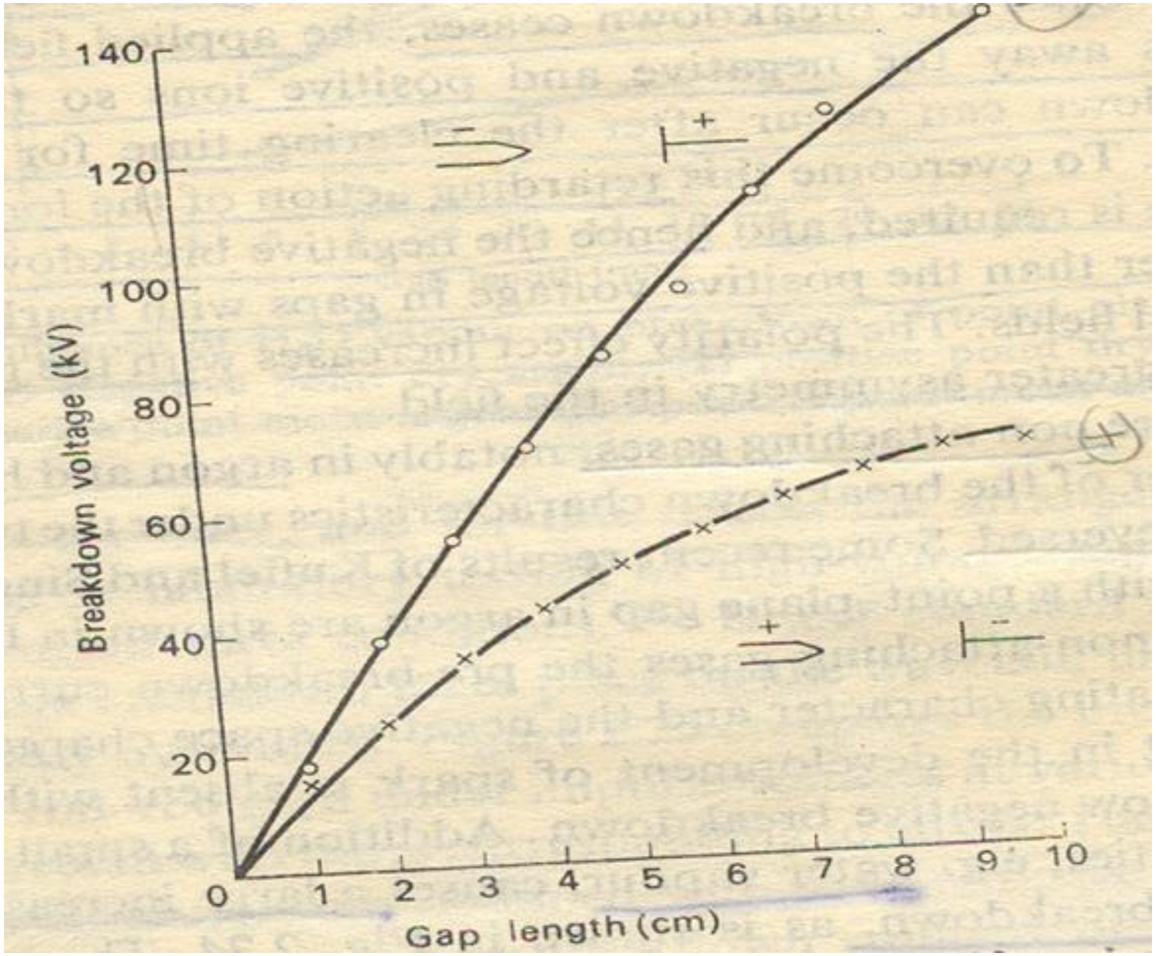


FIG. Breakdown voltage curves for nitrogen between a wire and a coaxial cylinder (radii 0·083 and 2·3 cm respectively); curve 1 refers to a positive wire, curve 2 to a negative wire.

- At high pressures the break down usually take place at a lower voltage when the smaller electrode is positive **fig** shows the direct break down voltage curves for a point plane-gap in Air.

DC breakdown curves for Air between 30 degree conical point and plane



- At high pressures the large polarity affect is generally attributed to the nature of the space charge of the pre-break down current
- In pure non-attaching gases notably in Argon and hydrogen the order of the break down characteristics under the two polarities is reversed
- Some recent results are obtained with point plane gap in Argon as shown in **fig in next slide**

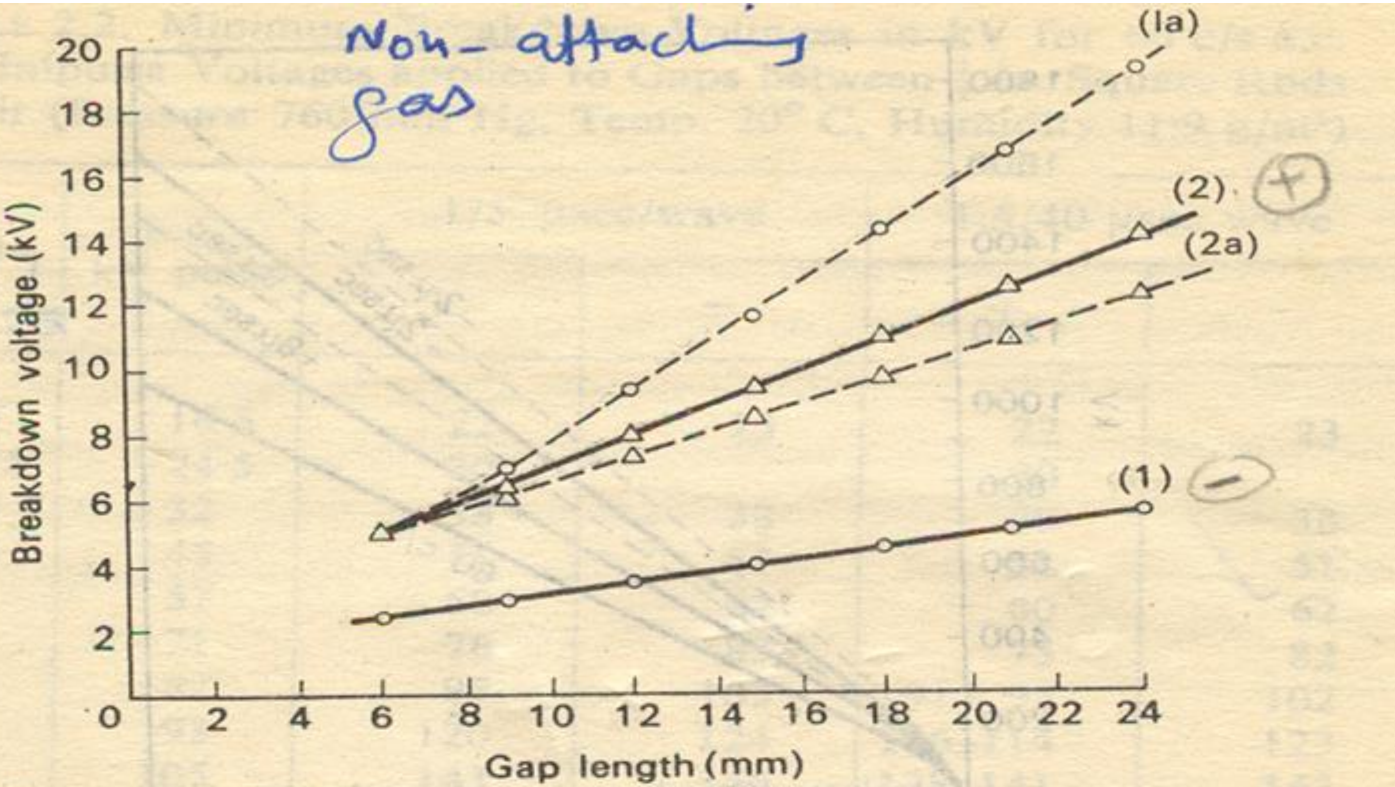
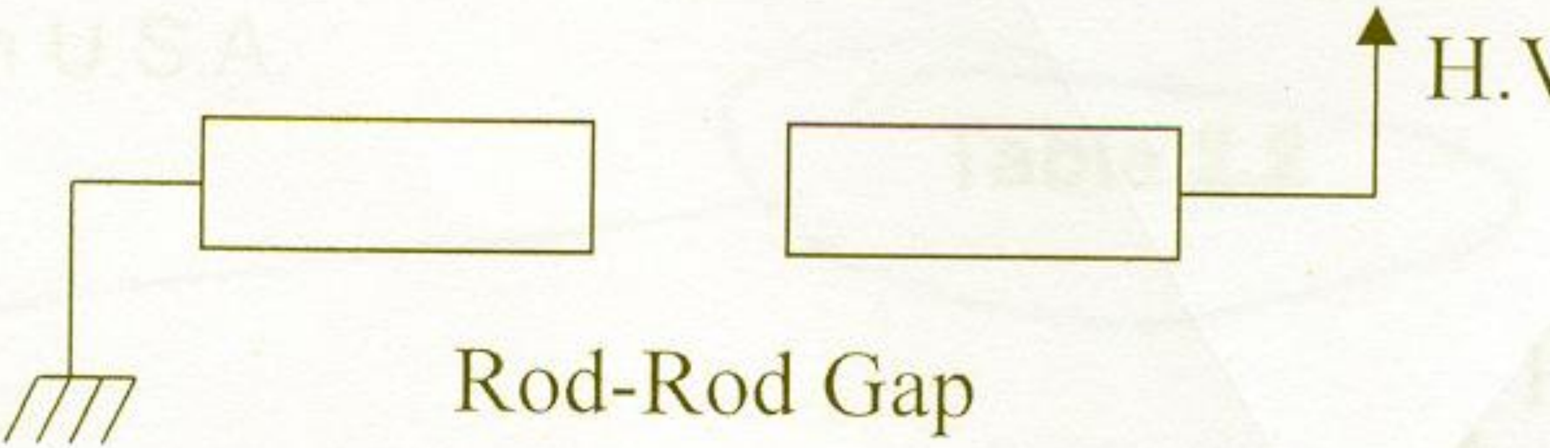


FIG. Influence of H_2O vapour on breakdown of point–plane gaps in argon. (1) Negative point dry argon; (2) positive point dry argon; (1a) negative point moist argon; (2a) positive point moist argon.

Addition of small amount of impurities e.g. Water, Vapors causes a large increase in negative break down voltage

The presence of water vapors shows a little effect on positive break down characteristics

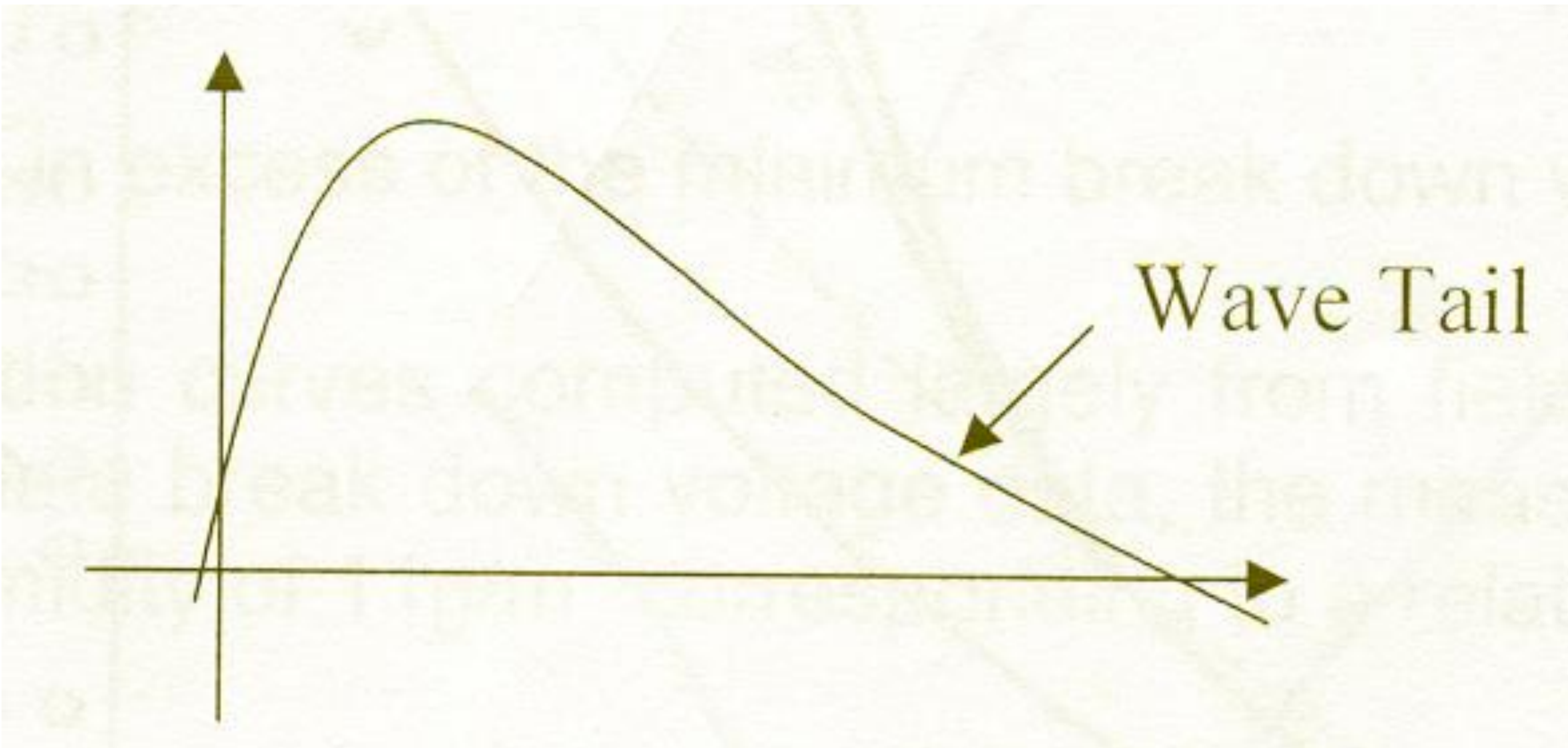


Rod-Rod Gap

Another non-uniform field electrode system which has been widely studied is Rod-Rod gap

Such geometry is found frequently in electrical apparatus. Most of the results have been obtained with rods of 1/2in or 5/8in square section with square cut ends

The break down characteristics of rod-gaps can be reproduced with reasonable accuracy and for this reason the arrangement is often used in Laboratory testing of High Voltages equipment under chopped wave conditions.


Wave Tail

- Under standard impulse-voltages the break down takes place on the wave-tail, unless the gap is highly over voted.
- **Fig in next slide** compares the break down values of rod-rod gaps under impulse voltages at various times on wave tail with those corresponding to 60cps
- The impulse breaks down values were obtained with 1.5/40μsec wave.

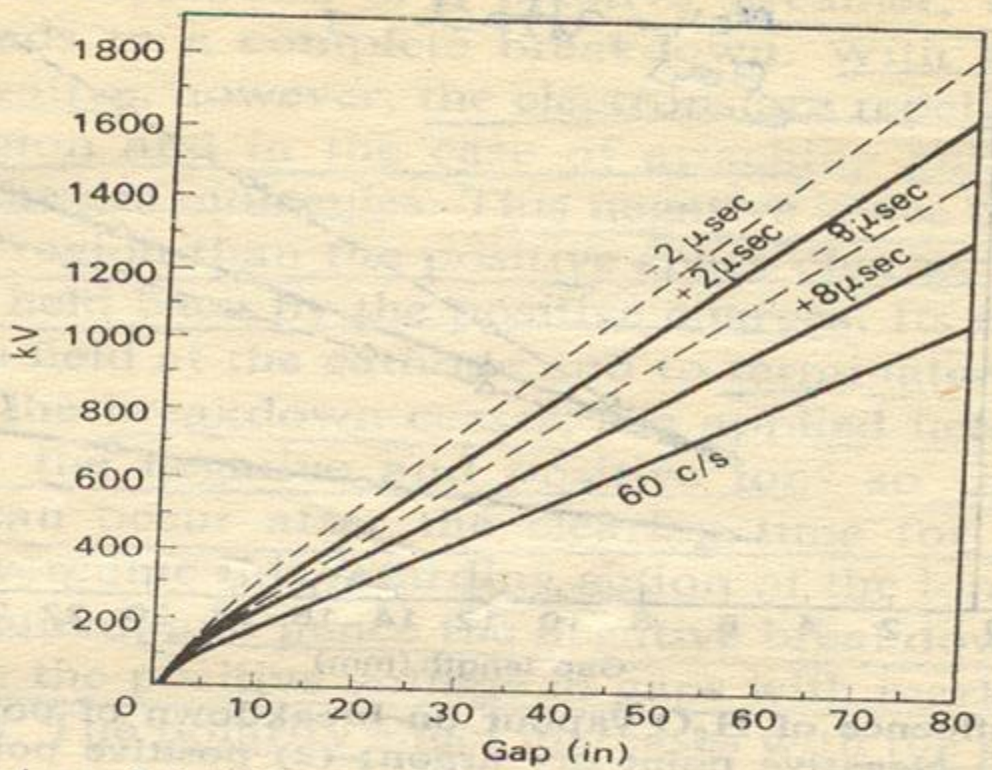
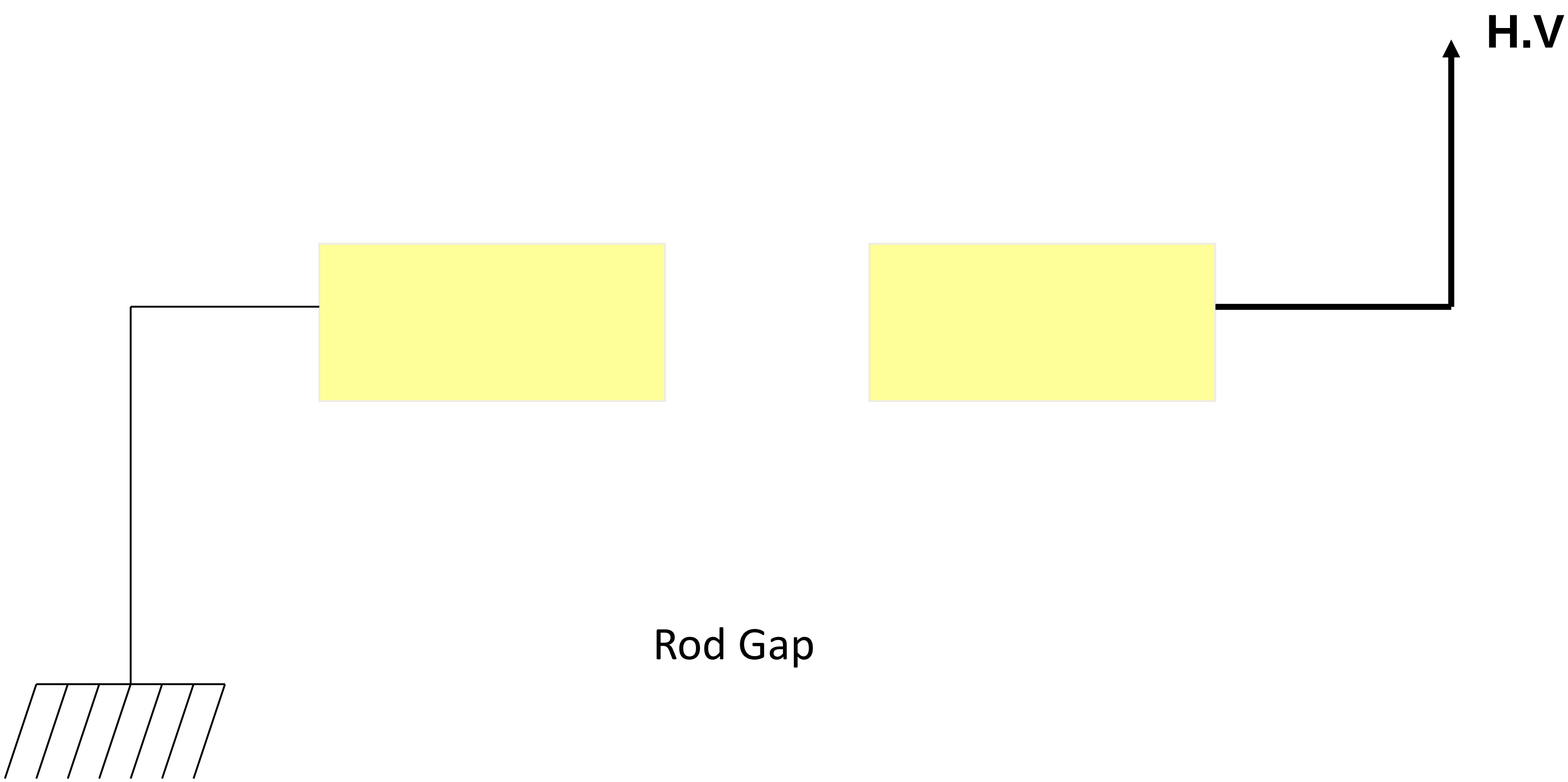


FIG. 60 c/s and 1·5/40 μsec impulse breakdown voltage curves for a rod–rod gap in air at n.t.p. with one rod earthed (absolute humidity of 6·5 grains/ft³).

BREAK DOWN IN NON-UNIFORM FIELDS



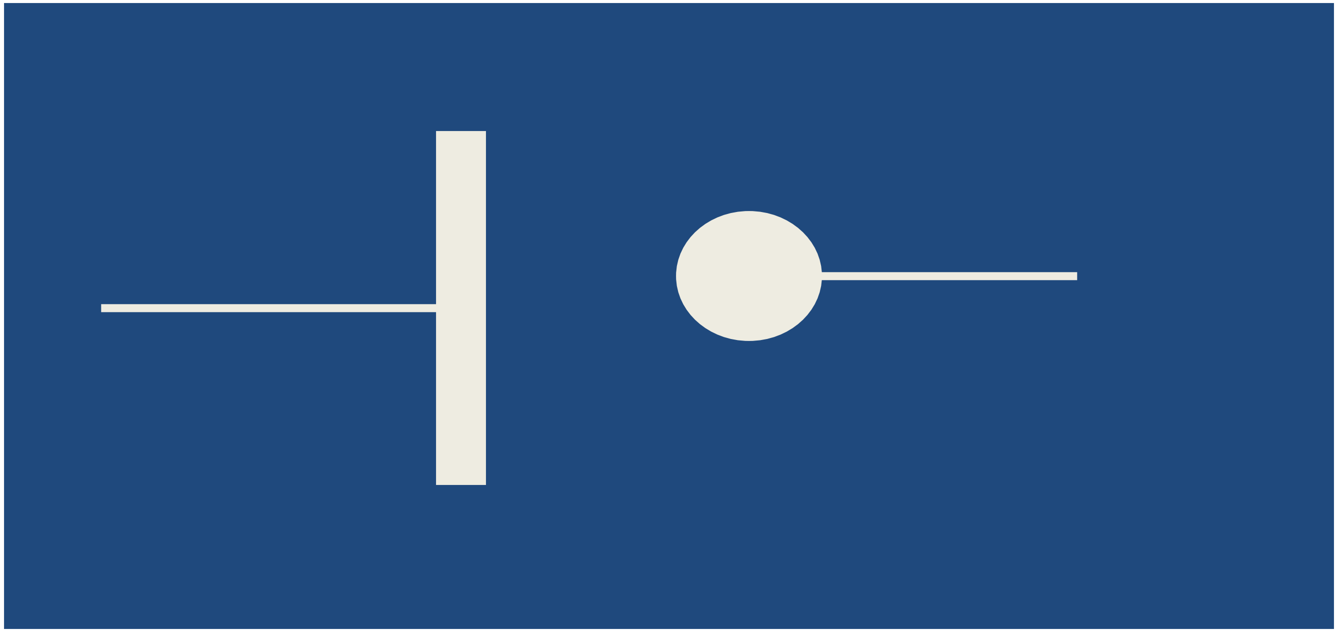
Rod Gap

Break down values of Rod-Gap are influenced by:

1) **Humidity**
2) **The effect depending on the wave-tail and wave-front (i.e. wave shape)**
3) **Polarity**
4) **Over voltage in excess of the minimum break down values.**

BREAK DOWN IN NON-UNIFORM FIELDS

SPHERE PLANE-GAPS



BREAK DOWN IN NON-UNIFORM FIELDS

SPHERE PLANE-GAPS

Such gaps geometry, although rarely found in any particular system, is useful in basic studies of spark charges, because the field distortion across such gap may be readily computed.

The break down characteristics observed by the author under the two polarities with conventional impulses voltages are shown in **fig in next slide**

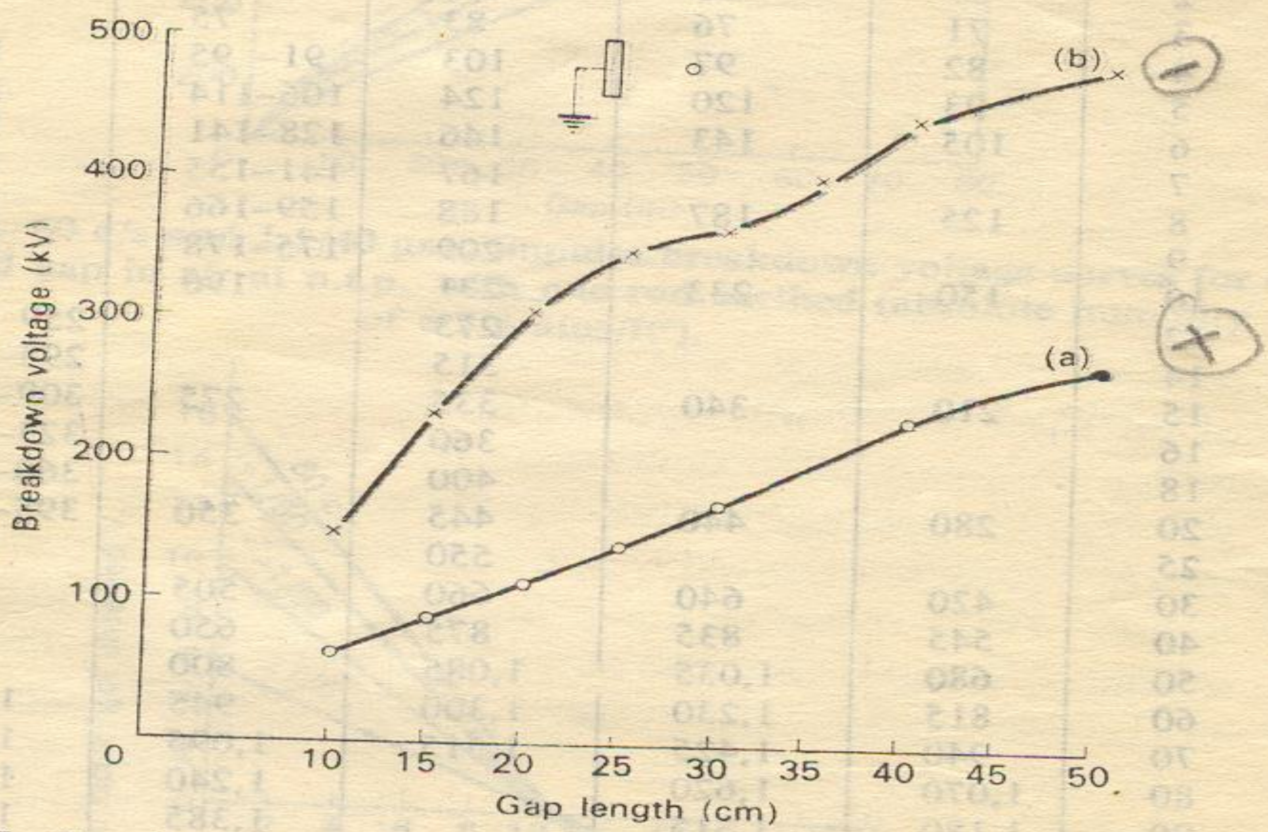


FIG. 2.27. Gap length–breakdown voltage characteristics; sphere–plane gaps (2 μsec front voltage); (a) sphere positive; (b) sphere negative.

BREAK DOWN IN NON-UNIFORM FIELDS

SPHERE PLANE-GAPS

- With positive high voltage sphere, the break down through positive leader which starts at the anode and travels along the gap to the cathode
- The positive leader requires relatively low voltage gradients for its propagation, consequently the observed break down values are low **as in previous slide**
- Under negative voltage several mechanisms have been proposed. Alibone and Meek recorded a negative leader from the cathode
- In the mean-time a positive leader starts from the anode and meets the negative leader in the middle of the gap.

Next Lecture

- Continued….