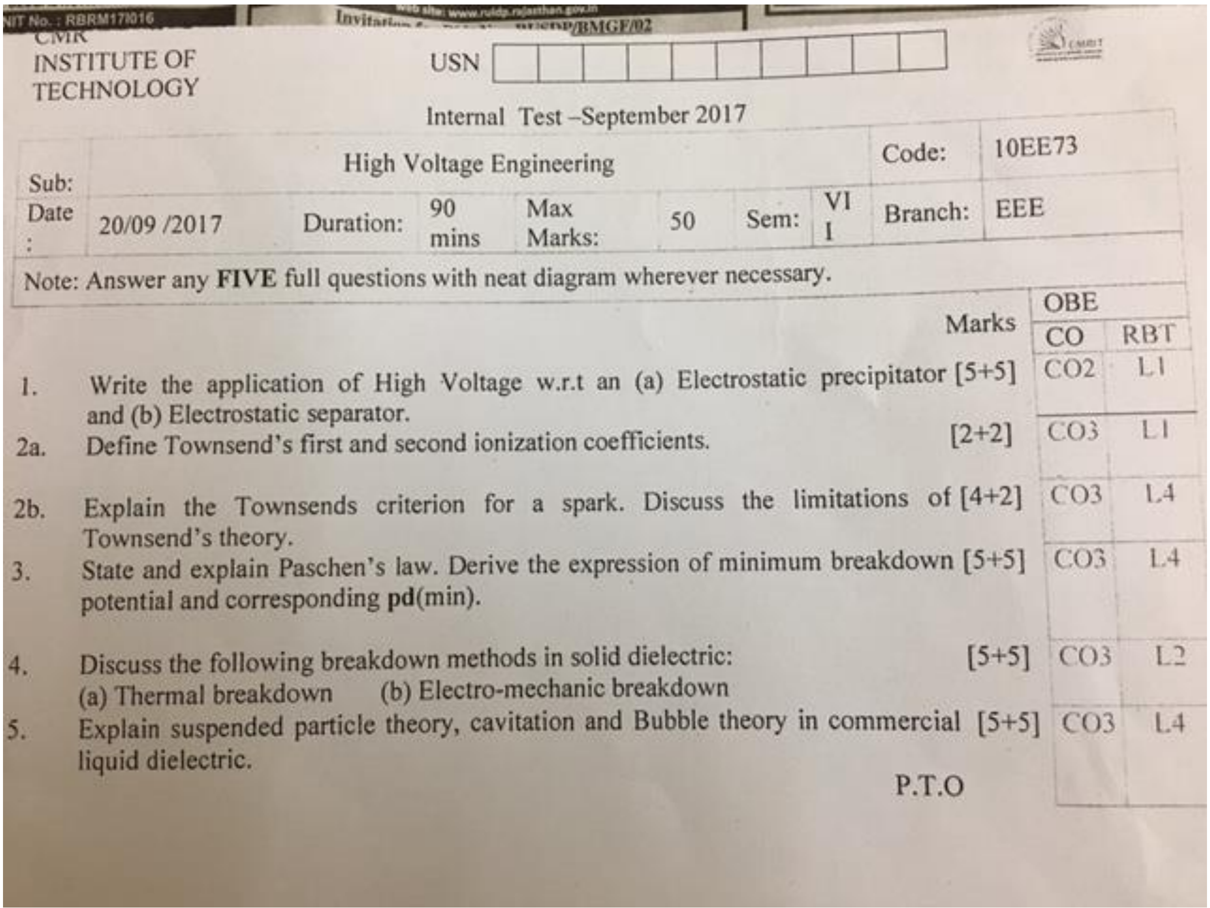

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Internal Test –September 2017

Sub:	High Voltage Engineering							Code:	10EE73
Date :	20/09 /2017	Duration:	90 mins	Max Marks:	50	Sem:	VI I	Branch:	EEE

Note: Answer any **FIVE** full questions with neat diagram wherever necessary.

		Marks	OBE CO	RBT
1.	Write the application of High Voltage w.r.t an (a) Electrostatic precipitator and (b) Electrostatic separator.	[5+5]	CO2	L1
2a.	Define Townsend's first and second ionization coefficients.	[2+2]	CO3	L1
2b.	Explain the Townsends criterion for a spark. Discuss the limitations of Townsend's theory.	[4+2]	CO3	L4
3.	State and explain Paschen's law. Derive the expression of minimum breakdown potential and corresponding **pd**(min).	[5+5]	CO3	L4
4.	Discuss the following breakdown methods in solid dielectric: (a) Thermal breakdown (b) Electro-mechanic breakdown	[5+5]	CO3	L2
5.	Explain suspended particle theory, cavitation and Bubble theory in commercial liquid dielectric.	[5+5]	CO3	L4

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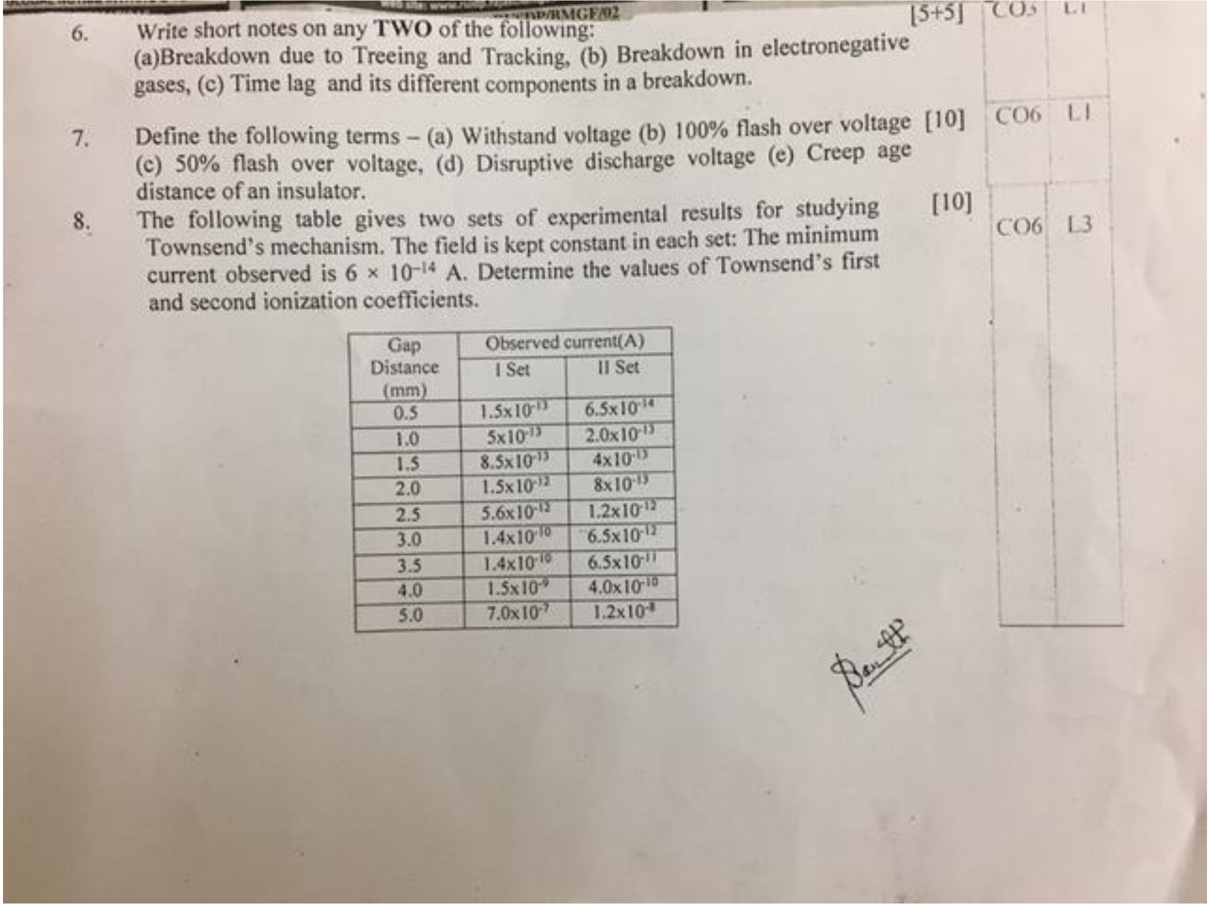
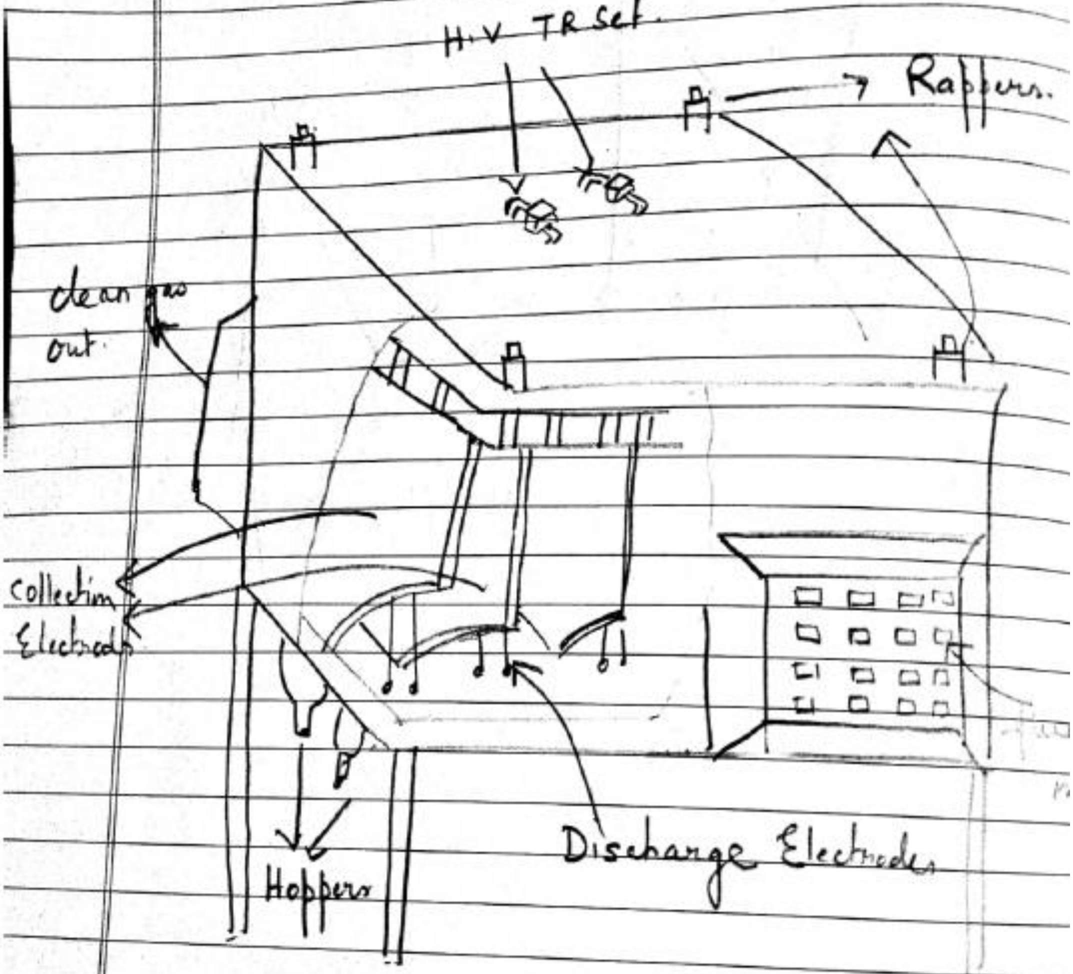


6.	Write short notes on any **TWO** of the following: (a)Breakdown due to Treeing and Tracking, (b) Breakdown in electronegative gases, (c) Time lag and its different components in a breakdown.	[5+5]	CO3	L1
7.	Define the following terms – (a) Withstand voltage (b) 100% flash over voltage (c) 50% flash over voltage, (d) Disruptive discharge voltage (e) Creep age distance of an insulator.	[10]	CO6	L1
8.	The following table gives two sets of experimental results for studying Townsend's mechanism. The field is kept constant in each set: The minimum current observed is 6×10^{-14} A. Determine the values of Townsend's first and second ionization coefficients.	[10]	CO6	L3

Gap Distance (mm)	Observed current(A)	
	I Set	II Set
0.5	1.5×10^{-13}	6.5×10^{-14}
1.0	5×10^{-13}	2.0×10^{-13}
1.5	8.5×10^{-13}	4×10^{-13}
2.0	1.5×10^{-12}	8×10^{-13}
2.5	5.6×10^{-12}	1.2×10^{-12}
3.0	1.4×10^{-10}	6.5×10^{-12}
3.5	1.4×10^{-10}	6.5×10^{-11}
4.0	1.5×10^{-9}	4.0×10^{-10}
5.0	7.0×10^{-7}	1.2×10^{-8}

1a



A typical ESP

Electrostatic Precipitation :-

E.S.Ps have been used for over half a century to control particulate emissions in many industries. They have more than 99% efficiency and can handle large exhaust gas volumes at high temperatures.

Application : cement plants and steel mills, that produce high temperature flue gases.

All ESPs contain six essential components :-

1) Discharge Electrodes : impart an electrical charge (usually -ve) to particles in a gas stream. The electrodes are usually small-diameter wires that hang vertically in the ESP or attached to the rigid frames. They can also be rigid masts or plates with needle strips.

2) Collection Electrodes : collect the charged particles. They can be either tubes or flat plates and they have a charge opposite to that of discharge electrodes.

3) Electrical systems (also called transformer-rectifier or T-R sets). are used to control the strength of electric field between the discharge and collection electrodes.

4) Rappers :- are mechanisms that provide vibration or shock to both the collection and discharge electrodes.

The vibration/shock causes the particles attached to these electrodes to fall into hoppers.

Hoppers are bins used to collect and temporarily store the particles removed during rapping. They are located at the bottom of an ESP.

Shell encloses the electrodes and supports the precipitator components in a rigid frame to maintain proper electrode alignment and configuration. The shell is covered with insulation to conserve heat and prevent corrosion. The outer shell wall is usually made of steel.

ESP System Operation :- The basic process underlying ESP operation is that pollutant particles in a gas stream are electrically charged (usually with a negative charge), which causes them to migrate towards and attach themselves to collection plates or tubes that are oppositely charged. The collection and discharge electrodes are then rapped in (in dry ESPs) or sprayed (in wet ESPs), which causes the particles attached to the electrodes to fall into a collection hopper.

A high voltage direct current is applied to a discharge wire (electrode) negatively charging it. Voltage to the wire is increased until a corona is produced aro the wire.

As the particle laden flue gases passes through the corona, the particles contai in the flue gas become negatively charged

⇒ Because the discharge electrodes are negatively charged and the collection electrodes are positively charged, a strong electrical field is created between them. This electrical field propels the negatively charged particles towards the positively charged collection electrodes, where the particles attach themselves.

Current from a standard power source is usually low-voltage alternating current.
TR set steps up the voltage from the standard 220 to 480 V to 20,000 to 70,000 V.
Rectifier part of the set converts this alternating current (a.c) to direct current (d.c).

What is sectionalization?

The discharge electrodes are arranged in fields, each powered by its own T-R set. This electrical partitioning known as sectionalization. This is used primarily because power input requirements differ at various locations within a precipitator. To adequately charge the incoming particles more power is needed at the inlet sections (as high dust concentrations can suppress corona current). High power is also needed at the outlet sections to collect small particles that exhibit high resistivity (resistance of a particle to accepting a charge).

But in the downstream fields, where dust loading is usually lighter, high power would create excessive sparking, so lower power is needed.

If only one T-R set were used in a precipitator, power input would have to be limited (to avoid excessive sparking), thus efficiency of entire unit would be reduced.

Types of ESPs :-

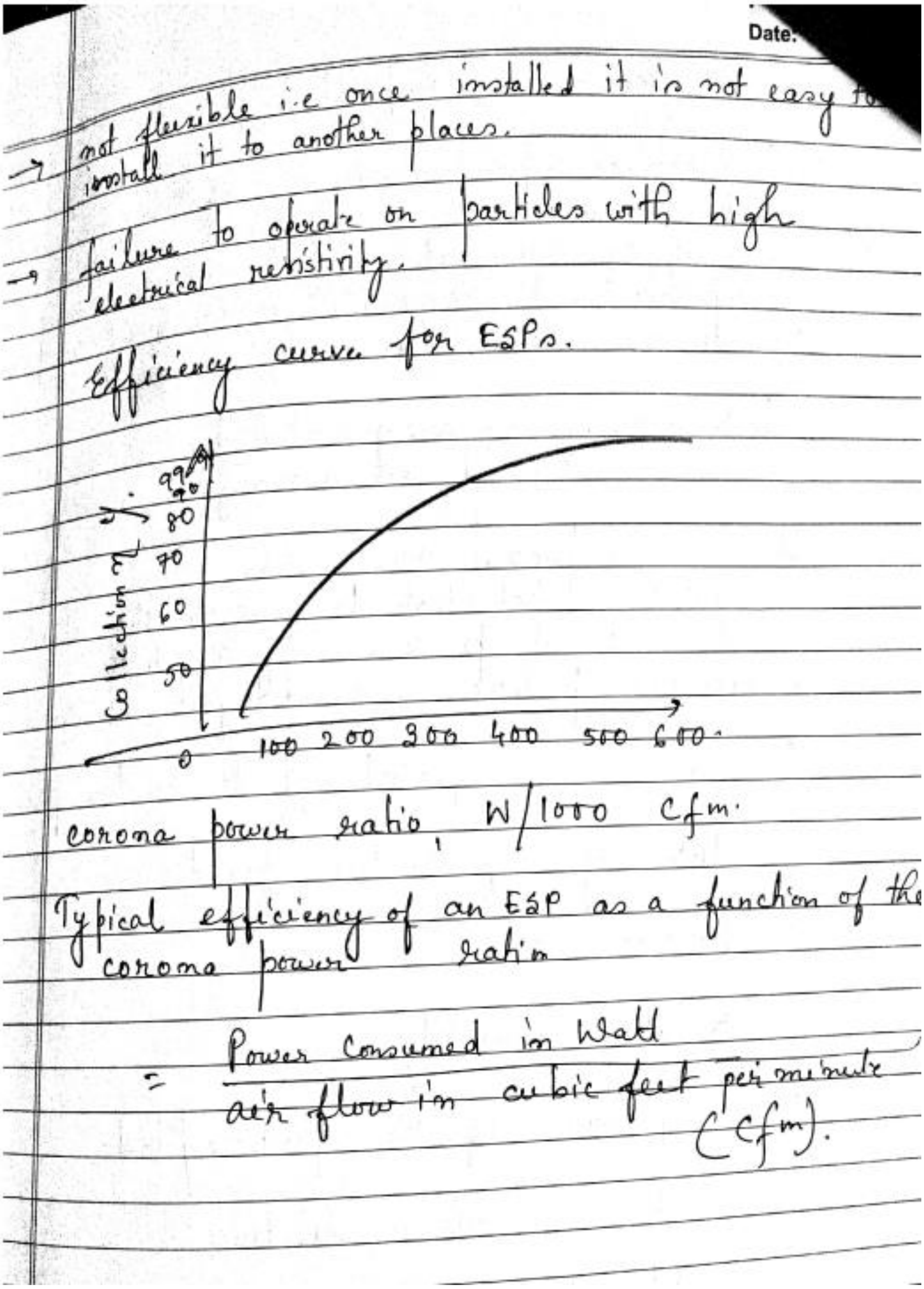
1. Plate wire ESP
2. Flat plate ESP
3. Tubular ESP.
4. Single stage ESP.
5. Two stage ESP
6. Cold side ESP.
7. Hot side ESP
8. Dry ESP
9. Wet ESP.

Advantages of ESPs :

→ Low operating cost.
→ Very high η even for smaller particles.
→ Temperature flexibility in design.
→ Ability to remove dry as well as wet particles.
→ Ability to handle very large gas flow rates with low pressure losses.

Disadvantages of ESPs :-

→ High capital cost (expensive to purchase & install)
→ Large coverage area.



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→ not flexible i.e once installed it is not easy to install it to another places.

→ failure to operate on particles with high electrical resistivity.

Efficiency curve for ESPs.

corona power ratio, W/1000 cfm.

Typical efficiency of an ESP as a function of the corona power ratio

$$= \frac{\text{Power consumed in Watt}}{\text{air flow in cubic feet per minute (cfm)}}$$

1b Electrostatis separator

Electrostatic Separation.

Electrostatic separation is one of those important unit operations where electrical conductivity property of mineral surface is used selectively to separate out desirable mineral from other undesirable minerals.

⇒ Electrostatic forces are generated by the action of an electric field on a charged particle.

⇒ In an ES process one needs a source of electrical potential to generate the electric field and a process by which the individual particles are charged electrically.

Factors have significant effect on the process

1. Intensity of electric field.
2. Particle size.
3. Relative humidity.
4. Temperature of the particle / bed.
5. Inter-electrode distance.

Advantages.

1) Electrostatic forces work on the particles

to be separated only, they do not affect the medium in which the particles are located.

2. The trajectories of the particles under the influence of the electric field follow the electric field lines. The electric field lines may be shaped to suit the particular application.

3. Direction of E.S forces may be reversed by either changing the polarity of the charge or the direction of the electrostatic field.

4. E.S forces may be arranged to work in combination with other forces such as gravitational or ~~cen~~ centrifugal forces.

5. E.S separation forces are independent of the substrate of the material on which the surface electric charge is generated. → depends on electric field and charge.

(~~May~~

Disadvantage :-

1. Limitation of max. ~~marks~~ mass that it can effectively work upon.

2. The size of the material to be separated should be very small which leads to the increase of comminution cost.

Comminution → the action of reducing a material, especially a mineral ore to minute particles or fragments.

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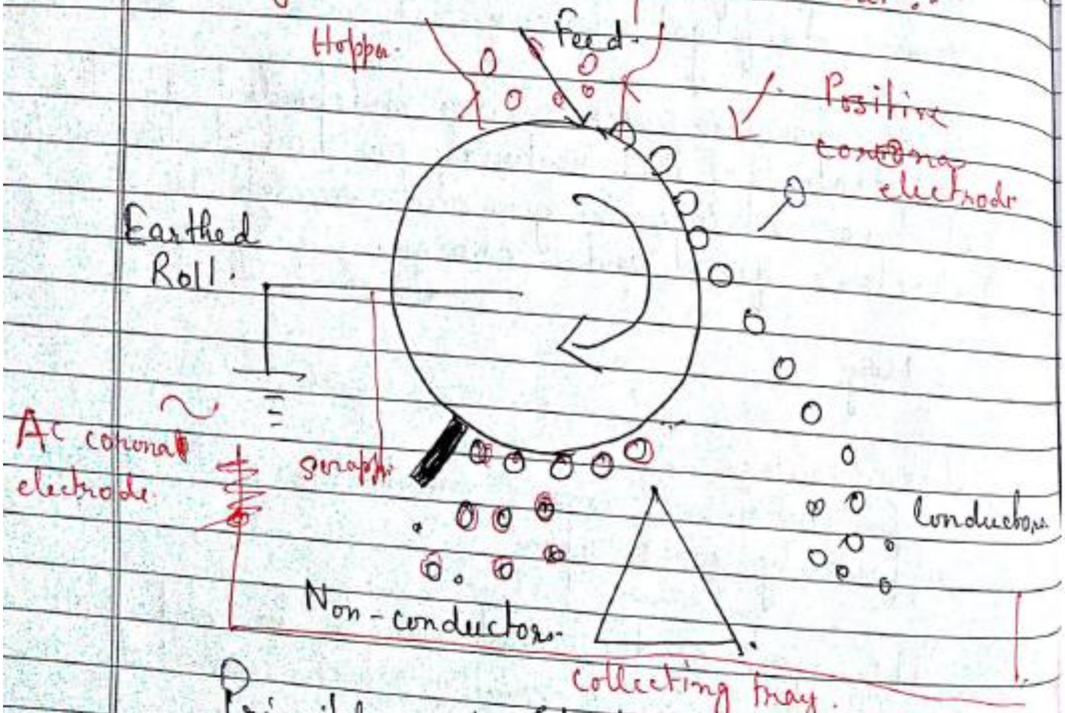
Electrification Process :- The separation by this process can be achieved by selective charging of particles, which is known as electrification.

They are Tribo electrification (electrically charged after friction)
Corona electrification.
Induction electrification.

Electrostatic separation Equipment:
Generally two types of equipment are used for separation. These are :

1 Drum type electrostatic separation unit :-



Principle of Electrostatic Separation.

This equipment consists of a rotating drum made of mild steel or some other conducting material, which is earthed through its support bearings. An electrode assembly, comprising of a brass tube in front of which is supported a length of fine wire, spans the complete length of role and is supplied with a fully rectified DC supply of up to 50 KV, usually of negative polarity.

The voltage supplied to the assembly should be such that ionisation of air takes place. → visible corona discharge. Arcing between the electrode and the roll must be avoided as it destroys ionisation. When ionisation occurs the minerals receive a spray discharge of electricity, which gives the poor conductors a high surface charge, causing them to be attracted to and pinned to the rotor surface. The particles of relatively high conductivity do not become charged as rapidly since the charge rapidly dissipates through the particles to the earthed rotor. These particles of higher conductivity follow a path.

A combination of pinning and lifting effects can be created by using a static electrode large enough to preclude corona discharge, following the electrode.

The conducting particles which are flung from the rotor are attracted to this static electrode and the compound process produces a very wide and distinct separation between conducting and no Conducting particles.

2. Plate type electrostatic separtion unit:-

A plate or screen type electrostatic separator is also used for separation. This type of equipment mainly consists of an oval type, high voltage electrode which induces the electric field. The material is feed through a sloping grounded plate under gravity. The electrostatic field is effectively shorted through the conducting particle.

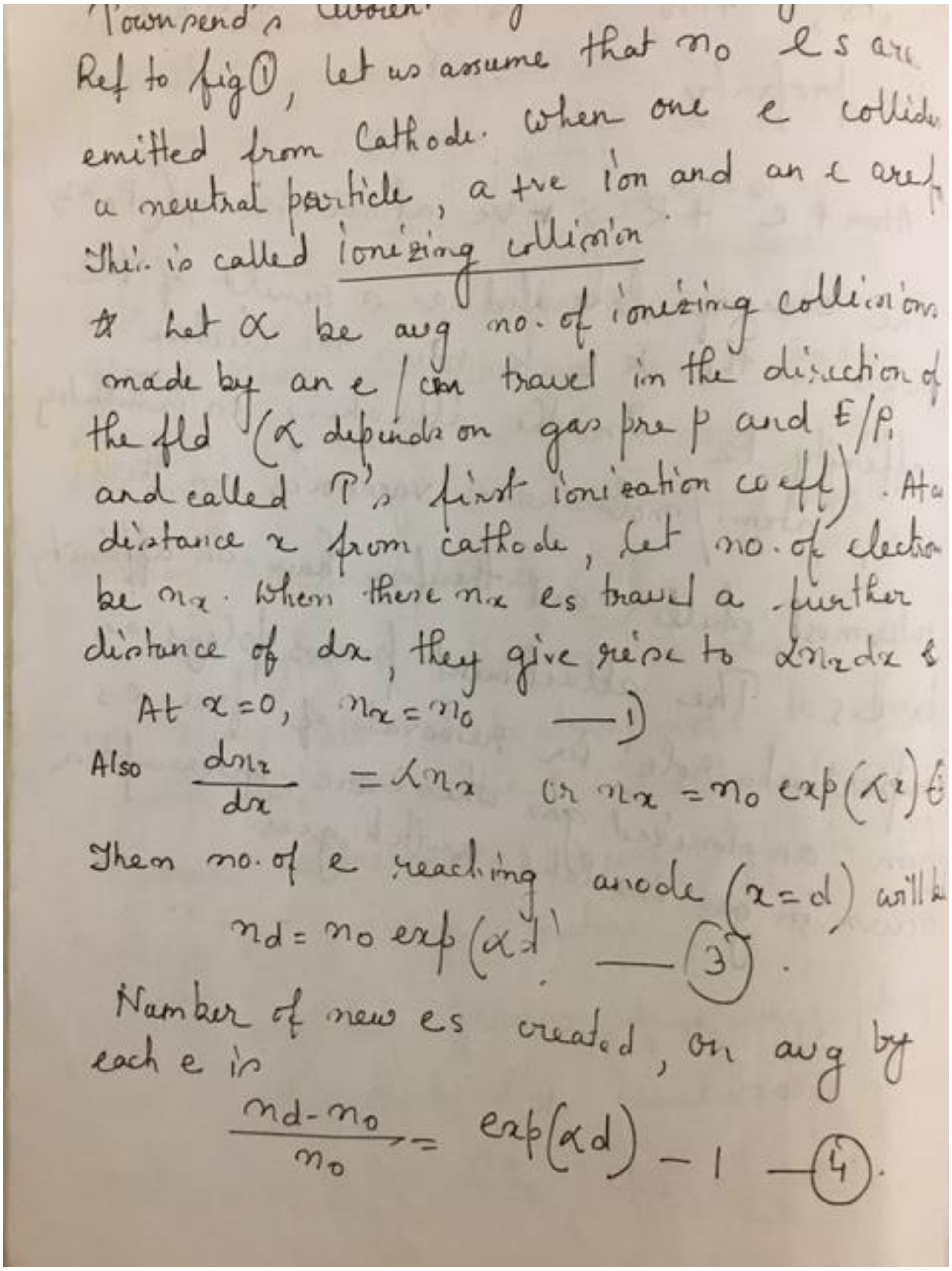
Application:

E.S. separation is used successfully for benefication of wide range of minerals.

1. Beach sand benefication.
2. Benefication of coal.

Benefication: In the mining industry benefication or benefication in extractive metallurgy is any process tha improves (benefits) the economic value of the ore removing gangue material.

2a



Townsend's

Ref to fig①, let us assume that n_0 es are emitted from Cathode. When one e collide a neutral particle, a +ve ion and an e are f. This is called ionizing collision.

☆ Let α be avg no. of ionizing collisions made by an e / cm travel in the direction of the fld (α depends on gas pre p and E/p, and called T's first ionization coeff). At a distance x from cathode, let no. of electrons be n_x. When these n_x es travel a further distance of dx, they give rise to $\alpha n_x dx$ e

At $x=0$, $n_x = n_0$ —1)

Also $\frac{dn_x}{dx} = \alpha n_x$ or $n_x = n_0 \exp(\alpha x)$ ②

Then no. of e reaching anode ($x=d$) will be

$$n_d = n_0 \exp(\alpha d) \quad — ③.$$

Number of new es created, on avg by each e is

$$\frac{n_d - n_0}{n_0} = \exp(\alpha d) - 1 \quad — ④.$$

∴ Avg current in gap, which is equal to no. of es travelling per second will be.

$$I = I_0 \exp(\alpha d) \quad — ⑤$$

where I_0 is initial current at the cathode.

Current Growth In The Presence of 2ndary Processes

Single avalanche process becomes complete when initial sets es reaches anode. Since amplification of es [exp (αd)] is occuring in fld, probability of additional new es being liberated in gap by other mechanisms ↑ and these new es create further avalanches. Other mechanisms are

i) +ve ion liberated may have sufficient energy to cause liberations of es from the cathode when they impinge on it

ii) Excited mols or atoms in avalanches may emits photons and this will lead to emission of es by photo-emission.

iii) Meta stable particle may diffuse back causing e emission.

$$\boxed{I = \frac{I_0 \exp(\alpha d}{1-\gamma.\left[\exp[\alpha d)-1\right]}}$$

Townsend's Criterion for Breakdown

Above eqn. gives total avg current in a gap before occurance of breakdown. As $d \uparrow$, denominator of eqn tends to zero and at some critical distance $d = d_s$ $\quad 1 - \gamma\left[\exp(\alpha d) - 1\right] = 0$.

for values $d < d_s$ $\quad I \simeq I_0$ and external source for supply of I_0 is removed, I becomes zero. If $d = d_s$, $I \to \alpha$ and current will be limited only by resis of power supply and ext ckt. This condition is called T's breakdown criterion and can be written as $\underline{\gamma\left[\exp(\alpha d) - 1\right] = 1}$

Normally $\exp(\alpha d)$ is very large and above eqn. reduces to $\boxed{\gamma \exp(\alpha d) = 1}$

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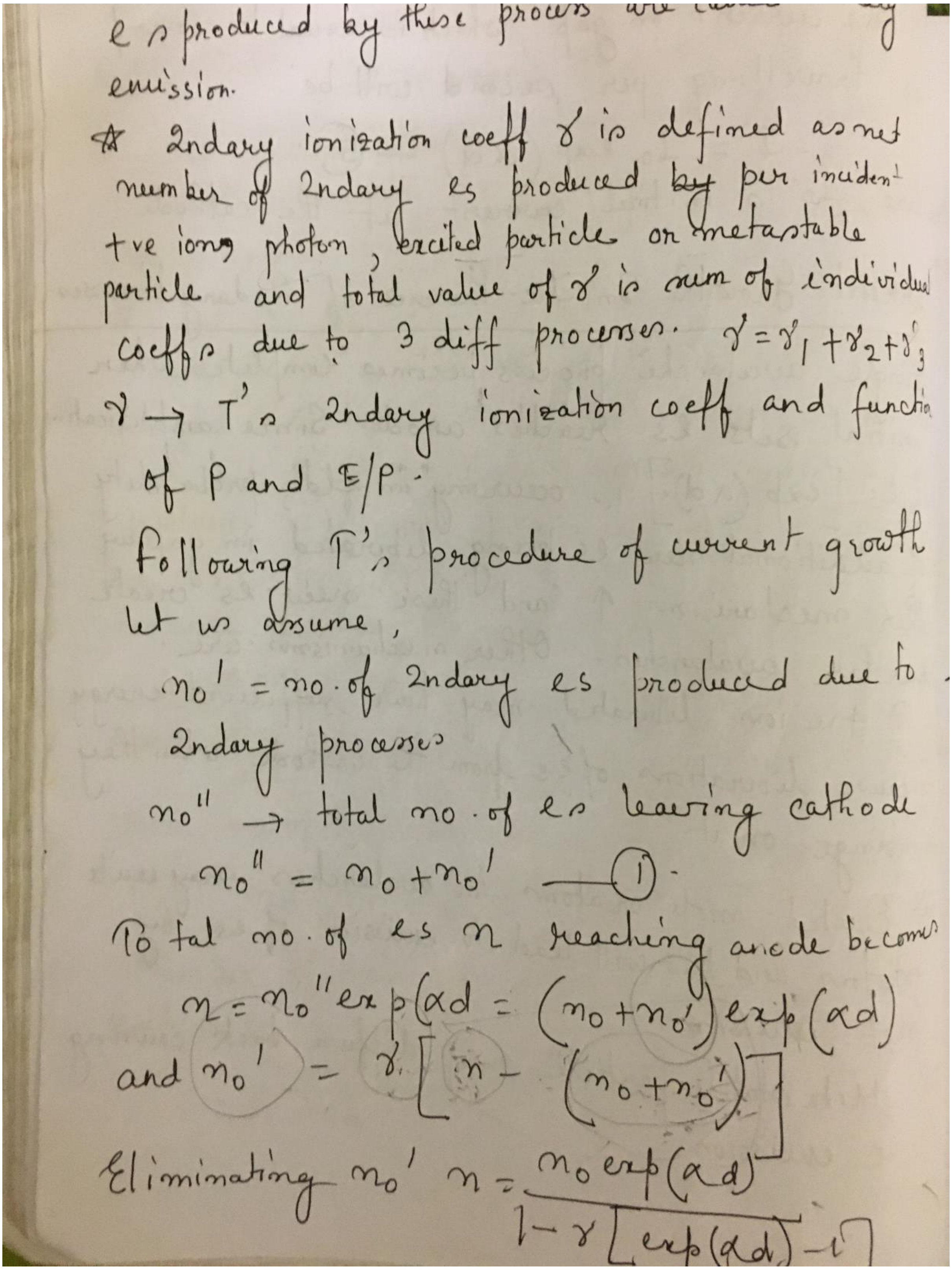


es produced by these process

emission.

☆ 2ndary ionization coeff γ is defined as net number of 2ndary es produced by per incident +ve ions photon, excited particle or metastable particle and total value of γ is sum of individual coeffs due to 3 diff processes. $\gamma = \gamma_1 + \gamma_2 + \gamma_3$

γ → T's 2ndary ionization coeff and function of P and E/P.

Following T's procedure of current growth let us assume,

n_0' = no. of 2ndary es produced due to 2ndary processes

n_0'' → total no. of es leaving cathode

$$n_0'' = n_0 + n_0' \quad ①$$

Total no. of es n reaching anode becomes

$$n = n_0'' \exp(\alpha d = (n_0 + n_0') \exp(\alpha d)$$

and $n_0' = \gamma \left[n - (n_0 + n_0') \right]$

Eliminating n_0' $n = \dfrac{n_0 \exp(\alpha d)}{1 - \gamma \left[\exp(\alpha d) - 1 \right]}$

2b **Limitation In Townsend's Mechanism**

- Townsend mechanism when applied to breakdown at atmospheric pressure was found to have certain drawbacks.

- A) according to the Townsend theory, current growth

occurs as a result of ionization processes only. But in practice, breakdown voltages were found to depend on the gas pressure and the geometry of the gap.

B) Mechanism predicts time lags of the order of 10-5S, while in actual practice breakdown was observed to occur at very short times of the order of 10-8S.

C) Townsend mechanism predicts a very diffused form of discharge, in actual practice, discharges were found to be filamentary and irregular.

The Townsend mechanism failed to explain all these observed phenomena and as a result, around 1940, Raether and, Meek and Loeb independently proposed the **Streamer theory**.

→ Townsend's Criteria

$\gamma\left[\exp(\alpha d) - 1\right]$ enables the evaluation of breakdown voltage of the gap by the use of appropriate values of α/p and γ co corresponding to E/p when the current is too low to damage the cathode and also space charge distortions are minimum.

→ Calculated and experimental values matches when gaps are short or long pressure is relatively ~~high~~ low.

⇒ Breakdown voltage for uniform field gaps as a function of gap length and gap pressure can be derived from threshold equation by expressing the ionization coefficient α/p as a function of field strength E and gas pressure p

[illegible]

$$\frac{\alpha}{p} = f\left(\frac{E}{p}\right).$$

$$\therefore \; e^{f(E/p)\,pd} = \frac{1}{\gamma} + 1$$

taking $\ln$ both sides:;

$$f\left(\frac{E}{p}\right)pd = \ln\left[\frac{1}{\gamma}+1\right] = K.$$

for uniform field $E = \frac{V_b}{d}$.

$$\therefore f\left(\frac{V_b}{pd}\right)\times(pd) = K.$$

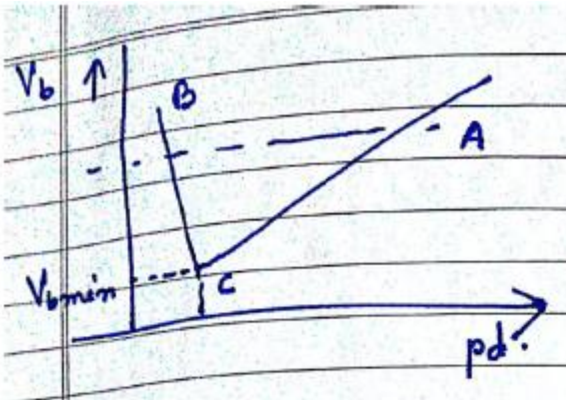
$$\therefore f\left(\frac{V_b}{pd}\right) = \frac{K}{pd}.$$

$$V_b = F(pd).$$

This shows the breakdown voltage of a uniform field gap is unique function of product of gap pressure and electrode material.

→ Paschen's Law.

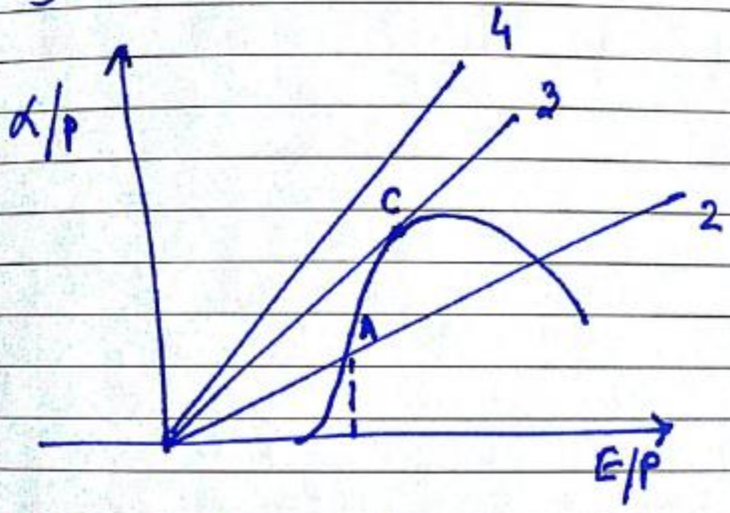
⇒ this relation does not mean that breakdown voltage is proportional to product pd, some region of the product pd the relation is linear.



Paschen's Law Curve

Let Experimentally obtained relation between ionization coeff of α/p and field strength (E/p)

$(E_b/p)_c \Rightarrow$ represents ~~on~~ onset of ionization



The Townsend's criteria

$$\alpha d = K.$$

$$\frac{\alpha}{p} \times \frac{V}{E} = \frac{K}{p} \quad \text{or} \quad \frac{\alpha}{p} = \frac{K}{V} \cdot \frac{E}{p}$$

This is equation to a straight line with slope equal to K/V, depending upon the value of K

Higher the voltage smaller slope

this line will intersect ionization curve at two points. A and B.

→ There must be two breakdown voltages at a constant pressure p, one corresponding to small value of gap length, i.e higher E ($E = V/$

i.e point B

⇒ other to the longer gap length i.e smaller E or E/p i.e point A.

⇒ At low values of voltage V, the slope of the straight line is large.

∴ no intersection between line and curve 1.

⇒ This means no breakdown occurs with small voltages below Paschen's minimum irrespective of the value of pd.

⇒ Point C on the curve indicates the lowest breakdown voltage or minimum sparking potential.

⇒ Spark over voltage corresponding to points A, B, C are shown in previous figure.

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To explain the fact that there exists a minimum sparking potential in the relati between sparking potential and gap lengt assuming p to be constant can be explai by considering the η of ionization of elect traversing the gap with different elect energies.

Assuming that the Townsend's second ionization coefficient γ is small for values $(pd) > (pd)_{min}$, electrons crossing the gap make more frequent collision with gas molecules than at $(pd)_{min}$, but the energy gained between the successive collision is small than at $(pd)_{min}$. Hence probability of ionization is lower unless the $V \uparrow$

In case of $(pd) < (pd)_{min}$, electron cross the gap without making any collisi and thus the sparking potential is high

point $(pd)_{min} \Rightarrow$ corresponding to highest ionization efficiency and hence minimum sparking potential.

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⇒ Analytical expression for minimum sparking potential can be obtained using general expression for α/p.

$$\frac{\alpha}{p} = Ae^{-Bp/E}$$

$$\therefore \alpha = pAe^{-Bp/E}$$

$$\alpha = pAe^{-Bpd/V_b}.$$

$$e^{Bpd/V_b} = \frac{pA}{\alpha}$$

$$\therefore \frac{1}{\alpha} = \frac{e^{Bpd/V_b}}{pA}.$$

$$\text{or } d.\frac{1}{\alpha d} = \frac{e^{Bpd/V_b}}{pA}.$$

$$\text{as } \alpha d = \ln\left(1 + \frac{1}{\gamma}\right).$$

$$\therefore d = \frac{e^{Bpd/V_b}}{pA} \times \alpha d.$$

$$= \frac{e^{Bpd/V_b}}{pA} \times \ln\left(1 + \frac{1}{\gamma}\right)$$

as γ = constant

$$\therefore \ln\left(1 + \frac{1}{\gamma}\right) = K$$

$$\therefore d = \frac{e^{Bpd/V_b}}{pA} \times K \quad — Ⓐ.$$

In order to obtain minimum sparking potential

$$V_b = f(pd).$$

Taking Logarithm in both sides.

$$\frac{Bpd}{V_b} \quad \ln \frac{Apd}{K}$$

$$V_b = \frac{Bpd}{\ln \frac{Apd}{K}}$$

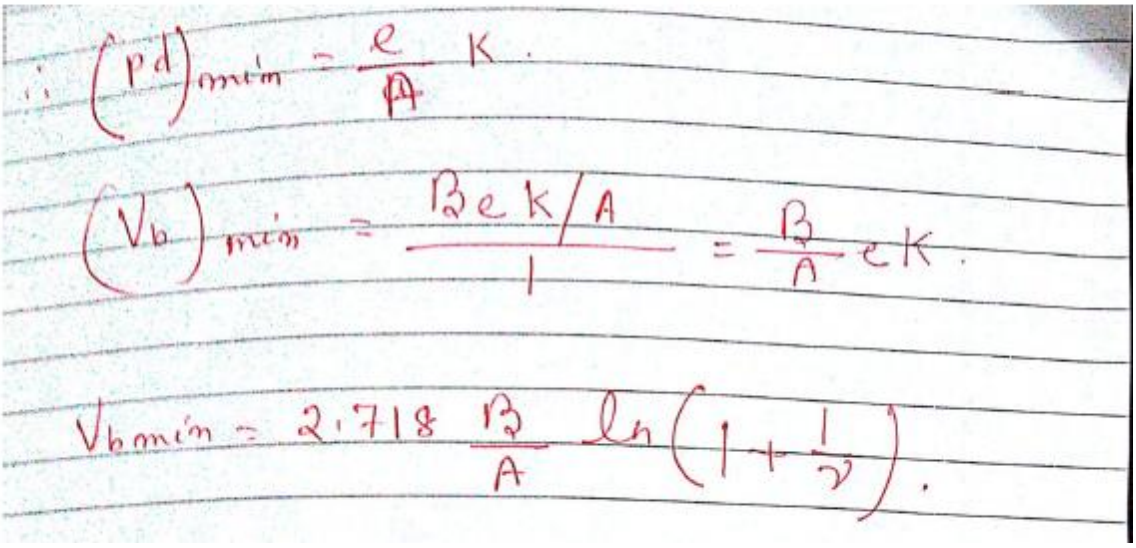
Differentiating V_b w.r.t pd and equating the derivative to zero.

$$\frac{dV_b}{d(pd)} = \frac{\ln \frac{Apd}{K} \times B - Bp\cancel{d} \cdot \frac{K}{\cancel{A}\cancel{p}\cancel{d}} \cdot \frac{\cancel{A}}{\cancel{K}}}{\left[\ln\left(\frac{Apd}{K}\right)\right]^2}$$

or $$\frac{1}{\ln \frac{Apd}{K}} = \frac{1}{\left[\ln\left(\frac{Apd}{K}\right)\right]^2}.$$

$$\ln\left(\frac{Apd}{K}\right) = 1.$$

$$\therefore \frac{Apd}{K} = e.$$



$$\therefore \ (pd)_{min} = \frac{e}{A} K.$$

$$(V_b)_{min} = \frac{B e K/A}{1} = \frac{B}{A} e K.$$

$$V_{b\,min} = 2.718 \frac{B}{A} \ln\left(1 + \frac{1}{\gamma}\right).$$

4.a **THERMAL BREAKDOWN**

- The breakdown voltage of a solid dielectric should increase with its thickness.
- This is true only up to a certain thickness above which the heat generated in the dielectric due to the flow of current determines the conduction.
- When an electric field is applied to a dielectric, conduction current, however small it may be, flows through the material.
- The current heats up the specimen and the temperature rises.
- The heat generated is transferred to the surrounding medium by conduction through the solid dielectric and by radiation from its outer surfaces.
- Equilibrium is reached when the heat used to raise the temperature of the dielectric, plus the heat radiated out, equals the heat generated. The heat generated under d.c. stress *E is given as*

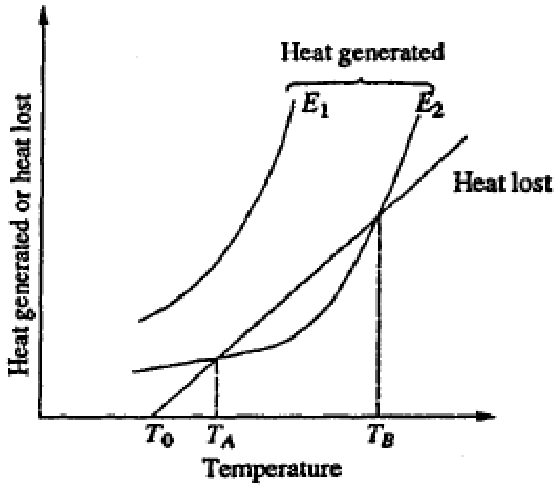
$$W_{d.c.} = E^2\sigma \qquad \mathrm{W/cm^3}$$

- where, б is the d.c. conductivity of the specimen.
- Under a.c. fields, the heat generated

$$W_{a.c.} = \frac{E^2 f \varepsilon_r \tan\delta}{1.8 \times 10^{12}} \qquad \mathrm{W/cm^3}$$

-
- where, *f*= frequency in Hz,
- δ= loss angle of the dielectric material, and

- *E- rms value.*
- The heat dissipated *(W_T)is given by*
- $$W_T = C_V \frac{dT}{dt} + \mathrm{div}\,(K \,\mathrm{grad}\, T)$$
- where, *C_V= specific heat of the specimen,*
- T= temperature of the specimen,
- *K = thermal conductivity of the specimen, and*
- t = time over which the heat is dissipated.
- Equilibrium is reached when the heat generated (Wa.c.or Wd.c.) becomes equal to Equilibrium is reached when the heat generated Wa.c.or Wd.c becomes equal to the heat dissipated *(WT).*
- *In actual practice there is always some heat that is radiated* out*).*
- *Breakdown occurs when Wd.c. or Wa.c. exceeds WT.*
- *The thermal instability condition is shown in Fig.*
- *Here, the heat lost is shown by a straight line*
- *the heat generated at fields E1 and E2 are shown by separate curves.*
- *At field EI breakdown occurs both at temperatures TA and TB*
- *In the temperature region of TA and TB heat generated is less than the heat lost for the field E2* ***the breakdown will not occur.***
- *This is of great importance to practising engineers, as most of the insulation failures in high voltage power apparatus occur due to thermal breakdown.*
- *Thermal breakdown sets up an upper limit for increasing the breakdown voltage when the thickness of the insulation is increased.*
- *For a given loss angle and applied stress, the heat generated is proportional to the frequency and hence thermal breakdown is more serious at high frequencies.*



-
- It can be seen
- since the power loss under a.c. fields is higher, the heat generation is also high, and hence the thermal breakdown stresses are lower under a.c. conditions than under d.c. conditions.

4b **ELECTROMECHANICAL BREAKDOWN**

When solid dielectrics are subjected to high electric fields, failure occurs due

to electrostatic compressive forces which can exceed the mechanical compressive strength.

If the thickness of the specimen is *4$ and is compressed to* a thickness *d under an applied voltage V, then the electrically developed compressive stress is in equilibrium*

$$\varepsilon_0 \varepsilon_r \frac{V^2}{2d^2} = Y \ln\left[\frac{d_0}{d}\right]$$

where *Y is the Young's modulus.*

Usually, mechanical instability occurs when

$$V^2 = d^2\left[\frac{2Y}{\varepsilon_0 \varepsilon_r}\right]\ln\left[\frac{d_0}{d}\right]$$

Substituting this in Equation the highest apparent electric stress before breakdown,

$$d/d_0 = 0.6 \text{ or } d_0/d = 1.67$$

- The above equation is only approximate as *Y depends on the mechanical stress.*
- When the material is subjected to high stresses the theory of elasticity does not hold good, and plastic deformation has to be considered

$$E_{\max} = \frac{V}{d_0} = 0.6\left[\frac{Y}{\varepsilon_0 \varepsilon_r}\right]^{\frac{1}{2}}$$

5. **Suspended Particle Theory**

- In commercial liquids, the presence of solid impurities cannot be avoided.
- These impurities will be present as fibres or as dispersed solid particles.
- The permittivity of these particles (**ε_1**) will be different from the permittivity of the liquid **(ε_2)**.
- If we consider these impurities to be spherical particles of radius r, and if the applied field is E, then the particles experience a force F, where

$$F = r^3 \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + 2\varepsilon_2} E \cdot \frac{dE}{dx}$$

- and this force is directed towards a place of higher stress if $\varepsilon_1 > \varepsilon_2$ and towards a place of lower stress if $\varepsilon_1 < \varepsilon_2$ when ε_1 is the permittivity of gas bubbles.
- The force given above increases as the permittivity of the suspended particles (ε_1) increases. If $\varepsilon_1 \rightarrow \infty$

$$F = r^3 \frac{1 - \varepsilon_2/\varepsilon_1}{1 + 2\varepsilon_2/\varepsilon_1} E \frac{dE}{dx}$$

Let $\varepsilon_1 \to \infty$

$$F = r^3 E \,.\, \frac{dE}{dx}$$

- Force will tend the particle to move towards the strongest region of the field.
- In a uniform electric field which usually can be developed by a small sphere gap, the field is the strongest in the uniform field region**. Here *dE/dx* → *0 so that the force on the particle is zero and the particle* remains in equilibrium**.
- Particles will be dragged into the uniform field region.
- Permittivity of the particles is higher than that of the liquid, the presence of particle in the uniform field region will cause flux concentration at its surface.
- Other particles if present will be attracted towards the higher flux concentration.
- The movement of the particle under the influence of electric field is opposed by the viscous force posed by the liquid and since the particles are moving into the region of high stress, diffusion must also be taken into account.
- We know that the viscous force is given by (Stoke's relation) *FV = 6πnrv where* η is the viscosity of liquid, *r the raidus of the particle and v the velocity of the particle.*
- Equating the electrical force with the viscous force we have

$$6\pi\eta r v = r^3 E \frac{dE}{dx} \quad \text{or} \quad v = \frac{r^2 E}{6\pi\eta} \frac{dE}{dx}$$

However, if the diffusion process is included, the drift velocity due to diffusion will be given by

$$v_d = -\frac{D}{N}\frac{dN}{dx} = -\frac{KT}{6\pi\eta r}\frac{dN}{Ndx}$$

where *D = KT/6πηr a relation known as Stokes-Einstein relation. Here K is Boltzmann's constant and T the absolute temperature.*

At any instant of time, the particle should have one velocity and, therefore, equation

$$v = vd$$

We have

$$-\frac{KT}{6\pi\eta r}\cdot\frac{dN}{Ndx}=\frac{r^2E}{6\pi\eta}\cdot\frac{dE}{dx}$$

$$\frac{KT}{r}\frac{dN}{N}=-r^2E\,dE$$

$$\frac{KT}{r}\ln N=-\frac{r^2E^2}{2}$$

- It is clear that the breakdown strength *E depends upon the concentration of particles N, radius r* of particle, viscosity η of liquid and temperature *T of the liquid.*
- It has been found that liquid with solid impurities has lower dielectric strength as compared to its pure form.
- larger the size of the particles impurity the lower the overall dielectric strength of the liquid containing the impurity.
- If there is only a single conducting particle between the electrodes, it will give rise to local field enhancement depending on its shape.
- If this field exceeds the breakdown strength of the liquid, local breakdown will occur near the particle, and this will result

in the formation of gas bubbles which may lead to the breakdown of the liquid.

- The values of the breakdown strength of liquids containing solid impurities was found to be much less than the values for pure liquids.
- The impurity particles reduce the breakdown strength, and it was also observed that the larger the size of the particles the lower were the breakdown strengths
- **Cavitation and the Bubble Theory**
- experimentally observed that in many liquids, the breakdown strength depends

strongly on the applied **hydrostatic pressure.**

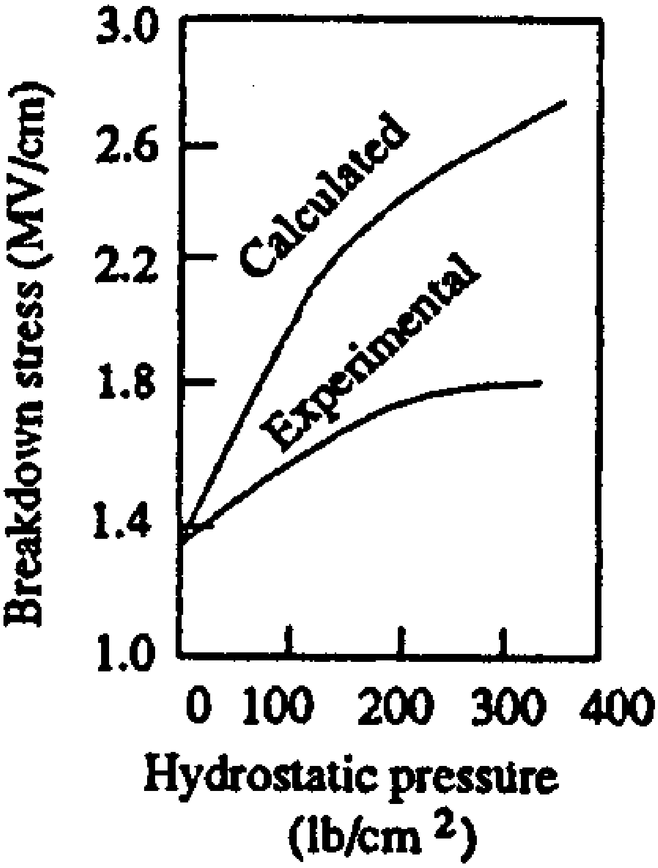
suggesting that a change of phase of the medium is involved in the breakdown process, which means kind of **vapour bubble** formed is responsible for breakdown.

The following processes are responsible for **formation of the vapour bubbles**:

- *(a)* **Gas pockets at the surfaces of the electrodes;**
- *(b)* **electrostatic repulsive forces between space charges which may be sufficient to overcome the surface tension**;
- (c) **gaseous products due to the dissociation of liquid molecules by electron collisions**
- *(d)* **vaporizations of the liquid by corona type discharge from sharp points and irregularities on the electrode surfaces**.
- Once a bubble is formed it will elongate in the direction of the electric field under the influence of electrostatic forces.
- The volume of the bubble remains constant during elongation.
- Breakdown occurs when the voltage drop along the length of the bubble becomes equal to the minimum value on the Paschen's curve
- The breakdown field is given as

$$E_0 = \frac{1}{(\varepsilon_1 - \varepsilon_2)}\left[\frac{2\pi\sigma(2\varepsilon_1 + \varepsilon_2)}{r}\left\{\frac{\pi}{4}\sqrt{\left(\frac{V_b}{2rE_0}\right)} - 1\right\}\right]^{\frac{1}{2}}$$

- Where б is the surface tension of the liquid,
- *ε 1 is the permittivity of the liquid,*
- *ε2 is* the permittivity of the gas bubble,
- *r is the initial radius of the bubble assumed as a* sphere
- *Vb is the voltage drop in the bubble (corresponding to minimum on the*
- Paschen's curve).
- From this equation, it can be seen that the breakdown strength depends on the initial size of the bubble which in turn is influenced by the hydrostatic pressure and temperature of the liquid.
- This theory does not take into account the production of the initial bubble and hence the results given by this theory do not agree well with the experimental results



6a

When a solid dielectric subjected to electrical stresses for a long time fails, normally two kinds of visible markings are observed on the dielectric materials. They are:

(a) *the presence of a conducting path across the surface of the insulation;*

(b) a mechanism whereby leakage current passes through the conducting path

finally leading to the formation of a spark.

Insulation deterioration occurs as a result of these sparks.

The spreading of spark channels during *tracking, in the form of the branches of a* tree is called **treeing**.

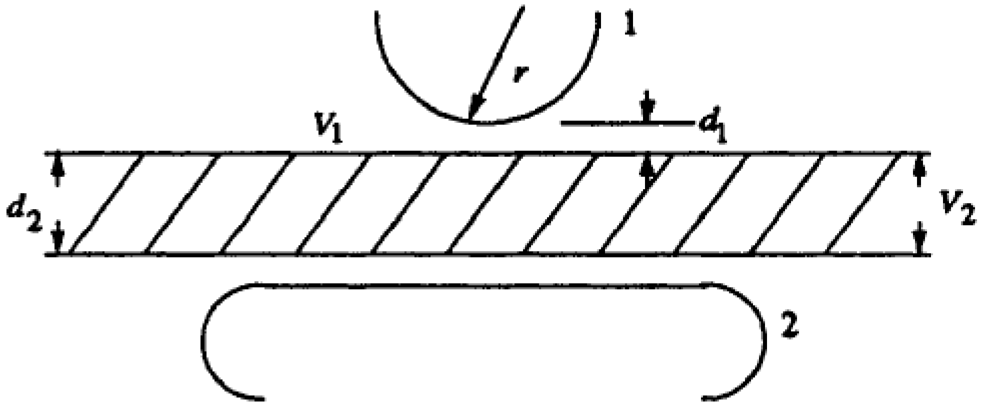
- Consider a system of a solid dielectric having a conducting film and two electrodes on its surface.
- In practice, the conducting film very often is formed due to moisture.
- On application of voltage, the film starts conducting, resulting in generation of heat, and the surface starts becoming dry.
- The conducting film becomes separate due to drying, and so sparks are drawn damaging the dielectric surface.

With organic insulating materials such as paper and bakelite, the dielectric carbonizes at the region of sparking, and the carbonized regions act as permanent conducting channels resulting in increased stress over the rest of the region.

This is a cumulative process, and insulation failure occurs when carbonized tracks bridge the distance between the electrodes.

This phenomena, called **tracking** is common between layers of bakelite, paper and similar dielectrics built of laminates

- **Treeing** occurs due to the erosion of material at the tips of the spark.
- Erosion results in the roughening of the surfaces, and hence becomes a source of dirt and contamination.
- This causes increased conductivity resulting either in the formation of a conducting path bridging the electrodes or in a mechanical failure of the dielectric.



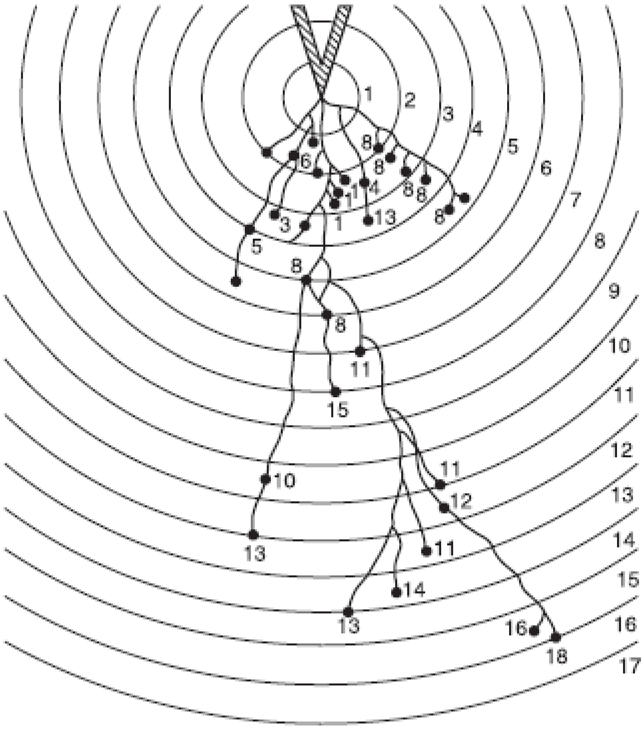
- **Arrangement for study of treeing phenomena. 1 and 2 are electrodes**
- When a dielectric material lies between two electrodes as shown in Fig. there is a possibility for two different dielectric media, the air and the dielectric, to come in series.

- The voltages across the two media are as shown *(V1 across the air gap, and V2* across the dielectric).
- The voltage *V1 across the air gap is given as,*

$$V_1 = \frac{V d_1}{d_1 + \left(\frac{\varepsilon_1}{\varepsilon_2}\right) d_2}$$

where *V is the applied voltage.*

- Since ε2>ε1, most of the voltage appears across **d1 the air gap.**
- *Sparking will* occur in the air gap and, charge accumulation takes place on the surface of the insulation.
- Sometimes the spark erodes the surface of the insulation.
- As time passes, breakdown channels spread through the insulation in an irregular "tree" like fashion leading to the formation of conducting channels.
- This kind of channelling is called **treeing**
- Usually, **tracking** occurs even at **very low voltages** of the order of about 100 V, whereas **treeing** requires **high voltage**.
- For testing of tracking, low and medium voltage tracking tests are specified.
- These tests are done at low voltages but for times of about 100 hr or more.
- The insulation should not fail.
- Sometimes the tests are done using 5 to 10 kV with shorter durations of 4 to 6 hr.
- The numerical value of voltage that initiates or causes the formation of a track is called the **"tracking index"** and this is used to qualify the surface properties of dielectric materials.
- Treeing can be prevented by having clean, dry, and undamaged surfaces and a clean environment.
- The materials chosen should be resistant to tracking.
- Sometimes moisture repellant greases are used.
- But this needs frequent cleaning and regreasing.
- Increasing creepage distances should prevent tracking, but in practice the presence of moisture films defeat the purpose.
- Usually, treeing phenomena is observed in capacitors and cables.

- 

6b

- It has been recognized that one process that gives high breakdown strength to a gas is the electron attachment in which free electrons get attached to neutral atoms or molecules to form negative ions.
- Since negative ions like positive ions are too massive to produce ionization due to collisions, attachment represents an effective way of removing electrons which otherwise would have led to current growth and breakdown at low voltages.
- The gases in which attachment plays an active role are called **electronegative gases.**
- The most common attachment processes encountered in gases are
- *(a) the direct* attachment in which an electron directly attaches to form a negative ion,
- (b) the dissociative attachment in which the gas molecules split into their constituent atoms and the electronegative atom forms a negative ion.
- These processes may be symbolically represented as:
- *(a) Direct attachment*
- $AB + e \longrightarrow AB^{-}.$
- *(b) Dissociative attachment*

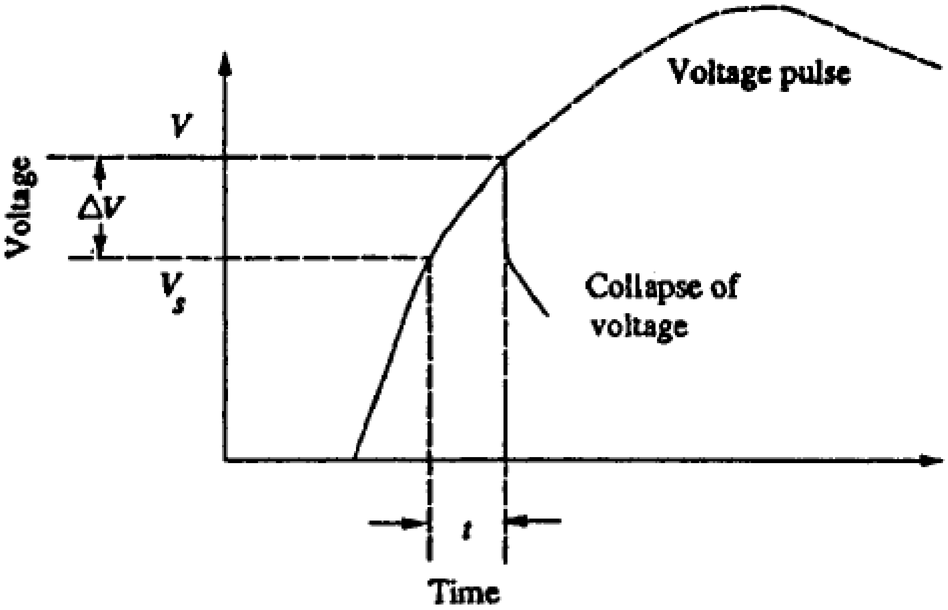
- $$AB + e \longrightarrow A + B^-$$
- A simple gas of this type is oxygen. Other gases are sulphur hexafluoride, freon, carbon dioxide, and fluorocarbons.
- In these gases, 'A” is usually sulphur or carbon atom, and 'B* is oxygen atom or one of the halogen atoms or molecules.
- With such gases, the Townsend current growth equation is modified to include ionization and attachment
- . **An attachment coefficient (η) is defined, as the number of attaching collisions made by one electron drifting one centimetre in the direction of the field.**
- Under these conditions the current reaching the anode, can be written as:
- $$I = I_0 \frac{[\{\alpha/(\alpha-\eta)\} \exp(\alpha-\eta)d] - [\eta/(\alpha-\eta)]}{1-\left\{\gamma \frac{\alpha}{(\alpha-\eta)} [\{\exp(\alpha-\eta)d\} - 1]\right\}}$$
- The Townsend breakdown criterion for attaching gases can also be deduced by equating the denominator to zero:
- $$\gamma \frac{\alpha}{(\alpha-\eta)} [\exp(\alpha-\eta)d - 1] = 1$$
- This shows that for $\eta < \alpha$ breakdown is always possible irrespective of the values of α, η, γ
- If on the other hand, $\eta > \alpha$ *Eq approaches an asymptotic form with* increasing value of d,
- $$\gamma \frac{\alpha}{(\alpha-\eta)} = 1 \; ; \text{ or } \alpha = \frac{\eta}{(1-\gamma)}$$
- This condition puts a limit *for E/p below which no breakdown is possible irrespective* of the value of *d, and the limit value is called the* ***critical E/p.*** *Critical E/p for SF6 is* 117 V cm^{-1} torr^{-1}, and for CCl2F2 it is 121 V cm^{-1} torr^{-1} (both at 2O^{0}C).

6c

- The mechanism of spark breakdown is considered as a function of ionization processes under uniform field conditions.

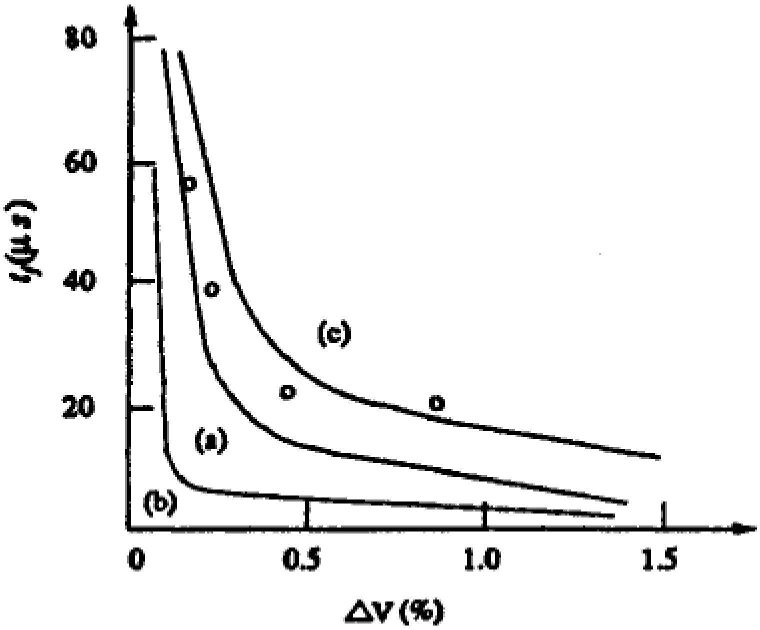
  But in practical engineering designs, the breakdown due to rapidly changing voltages or impulse voltages is of great importance.

- Actually, there is a time difference between the application of a voltage sufficient to cause breakdown and the occurrence of breakdown itself.
- This time difference is called the **time lag.**
- The Townsend criterion for breakdown is satisfied, only if at least one election is present in the gap between the electrodes.
- In the case of applied d.c. or slowly varying (50 Hz a.c) voltages, there is no difficulty in satisfying this condition.
- With rapidly varying voltages of short duration (=10-6 *s), the initiatory electron may not* be present in the gap.
- In the absence of such an electron breakdown cannot occur.
- The time *t which lapses between the application of the voltage sufficient to cause* breakdown and the appearance of the initiating electron is called a **statistical time lag** (ts)of the gap.
- The appearance of electrons is usually statistically distributed.
- After the appearance of the electron, a time *tt is required for the ionization processes to* develop fully to cause the breakdown of the gap
- this time is called the **formative time lag** *(tt).*
- *The total time ts + tt=t is called the **total time lag**.*
- Time lags are of considerable practical importance.
- For breakdown to occur the applied voltage *V should be greater than the static breakdown voltage Vs as shown* in Fig.
- The difference in voltage ΔV = V- *Vs is called the **overvoltage***
- ratio *V/Vs is called the **impulse ratio**.*



Breakdown on the front of the applied impulse voltage wave

- *The variation of* **t***t with overvoltage (ΔV)* is shown in Fig.



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7a ***Withstand Voltage***

- The voltage which has to be applied to a test object under specified conditions in a **withstand test** is called the **withstand voltage**

7b *Hundred Per Cent Flashover Voltage*

The voltage that causes a flashover at each of its applications under specified conditions when applied to test objects is specified as **hundred per cent flashover voltage**.

7c *Fifty Per Cent Flashover Voltage*

- This is the voltage which has a probability of **50% flashover,** when applied to a test object.
- This is normally applied in impulse tests in which the loss of insulation strength is temporary

7d *Disruptive Discharge Voltage*

- This is defined as the voltage which produces the loss of dielectric strength of an insulation.
- It is that voltage at which the electrical stress in the insulation causes a failure which includes the collapse of voltage and passage of current.
- In solids, this causes a permanent loss of strength.
- In liquids or gases only temporary loss may be caused.
- When a discharge takes place between two electrodes in a gas or a liquid or over a solid surface in air, it is called **fiashover**.
- If the discharge occurs through a solid insulation it is called **puncture**.

7e *Creepage Distance*

It is the shortest distance on the contour of the external surface of the insulator unit or between two metal fittings on the insulator.

Solution: 1st Set. Since there is gradual increase in current upto gap distance of 3 mm, slope between any two points

$$\left(\frac{\ln I/I_0}{x}\right)$$

will give us the value of α.

Let us take gap distances of 2 and 2.5 mm.

The respective $\ln I/I_0$ are

$$\ln\left(\frac{1.5\times10^{-12}}{6\times10^{-14}}\right) = 3.2188$$

and

$$\ln\left(\frac{1.5\times10^{-12}}{6\times10^{-14}}\right) = 4.5362$$

$$\therefore \quad \text{The slope} \qquad = \frac{4.5362 - 3.2188}{0.05} = 26.34$$

Since there is sudden rise in current at the last observation, this is used to evaluate γ.

We know that

or $$I = \frac{I_0 e^{\alpha x}}{1 - \gamma\,(e^{\alpha x} - 1)}$$

or $$\frac{I}{I_0} = \frac{7}{6}\times10^{7} = \frac{e^{26.34\times0.5}}{1-\gamma(e^{13.17}-1)}$$

$$= \frac{5.24\times10^{5}}{1-5.24\times10^{5}\,\gamma}$$

or $$\frac{7}{6}\times10^{7}\,\frac{1}{5.24\times10^{5}} = \frac{1}{1-5.24\times10^{5}\,\gamma}$$

or $$0.0449 = 1 - 5.24\times10^{5}\,\gamma$$

or $$0.9551 = 5.24\times10^{5}\,\gamma$$

or $$\gamma = 0.182\times10^{-5}\ /\text{cm}.$$

Set-II. For the same gap distance the slope will be $\alpha = \ln(12/8)/0.05 = 8.1$ collisions/cm and therefore

$$\frac{I}{I_0} = 2 \times 10^5 = \frac{e^{8.1 \times 0.5}}{1 - \gamma(e^{4.05} - 1)}$$

$$2 \times 10^5 = \frac{57.39}{1 - \gamma\,(56.39)}$$

or $$\frac{200 \times 10^3}{57.39} = 3.4849 \times 10^3 = \frac{1}{1 - 56.39\gamma}$$

$$2.87 \times 10^{-4} = 1 - 56.39\ \gamma$$

$$56.39\gamma = 1.0$$

or $$\gamma = 1.7 \times 10^{-2} \text{ collisions/cm}$$