CMR INSTITUTE OF TECHNOLOGY		USN							
Internal Assesment Test I – November 2021									
Sub:	HIGH VOLTAGE ENGINEERING							Code:	18EE56
Date:	13.11.2021	Duration:	90 mins	Max Marks:	50	Sem:	V	Section:	A,B

Note: Answer any **FIVE FULL** Questions
Sketch neat figures wherever necessary. Answer to the point. **Good luck!**

		Marks	OBE CO	RBT
1	Define Townsend’s first and second ionization coefficients. Explain the Townsends criterion for a spark. Discuss the limitations of Townsend’s theory.	[10]	CO1	L2
2 (a)	State and explain Paschen’s law.	[5]	CO1	L2
(b)	Derive the expression of minimum breakdown potential and corresponding pd(min).	[5]	CO1	L3
3(a)	Explain in detail the Streamer’s or Kanal mechanism of breakdown of gaseous insulating medium.	[5]	CO1	L2
(b)	What will be the breakdown voltage of a spark gap in a gas at a pressure of P = 760 torr at 25^0C if A = 15/cm, B = 360/cm, d = 1mm and $\gamma = 1.5 \times 10^{-4}$.	[5]	CO1	L3
4	Discuss the following breakdown methods in solid dielectric: (a) Thermal breakdown (b) Intrinsic breakdown , (c) Electromechanical breakdown	[10]	CO2	L2
5	Write short notes on different types of secondary ionization.	[10]	CO1	L3
6(a)	What is time-lag? Discuss its components and the factors which affect these components.	[5]	CO1	L2
(b)	In an experiment in a certain gas, it was found that the steady state current is 5.5×10^{-8} A at 8 kV at a distance of 0.4 cm between the plane electrodes. Keeping the field constant and reducing the distance to 0.1 cm results in a current of 5.5×10^{-9} A Calculate Townsend’s primary ionization coefficient α.	[5]	CO1	L3
7	What is a cascaded transformer? Explain why cascading is done?	[10]	CO3	L2

	Describe with neat diagram a three stage cascaded transformer. Label the power ratings of various stages of the transformer.			

1. Define Townsend’s first and second ionization coefficients. Explain the Townsends criterion for a spark. Discuss the limitations of Townsend’s theory

Townsend’s Theorem

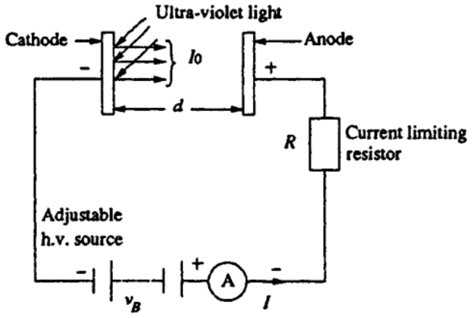
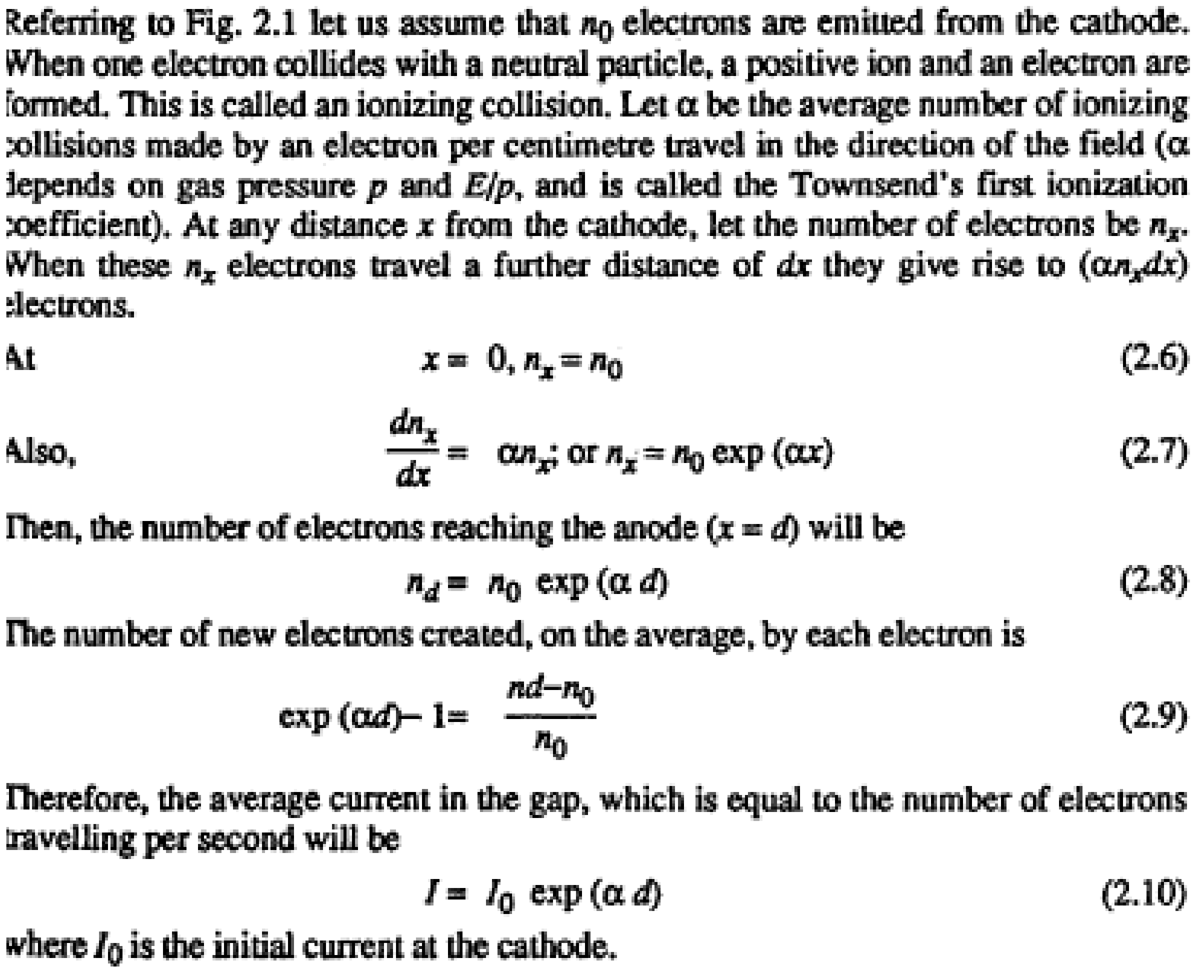


Fig. 2.1 Arrangement for study of a Townsend discharge

α, the average number of ionizing collisions made by an electron per centimetre travel in the direction of the field (α depends on gas pressure *p* and *EIp,)*and is called the Town send's first ionization coefficient).

The secondary ionization coefficient γ is defined in the same way as a, as the net number of secondary electrons produced per incident positive ion, photon, excited particle, or metastable particle, and the total value of γ is the sum of the individual coefficients due to the three different processes, i.e., γ = γ1 +γ2+ γ3=γ is called the Townsend's secondary ionization coefficient and is a function of the gas pressure *p* and *E/p.*



Referring to Fig. 2.1 let us assume that n_0 electrons are emitted from the cathode. When one electron collides with a neutral particle, a positive ion and an electron are formed. This is called an ionizing collision. Let α be the average number of ionizing collisions made by an electron per centimetre travel in the direction of the field (α depends on gas pressure p and E/p, and is called the Townsend's first ionization coefficient). At any distance x from the cathode, let the number of electrons be n_x. When these n_x electrons travel a further distance of dx they give rise to ($\alpha n_x dx$) electrons.

At
$$x = 0, n_x = n_0 \tag{2.6}$$

Also,
$$\frac{dn_x}{dx} = \alpha n_x; \text{ or } n_x = n_0 \exp(\alpha x) \tag{2.7}$$

Then, the number of electrons reaching the anode ($x = d$) will be

$$n_d = n_0 \exp(\alpha d) \tag{2.8}$$

The number of new electrons created, on the average, by each electron is

$$\exp(\alpha d) - 1 = \frac{nd - n_0}{n_0} \tag{2.9}$$

Therefore, the average current in the gap, which is equal to the number of electrons travelling per second will be

$$I = I_0 \exp(\alpha d) \tag{2.10}$$

where I_0 is the initial current at the cathode.

CURRENT GROWTH IN THE PRESENCE OF SECONDARY PROCESSES

The single avalanche process described in the previous section becomes complete when the initial set of electrons reaches the anode. However, since the amplification of electrons [exp(od)] is occurring in the field, the probability of additional new electrons being liberated in the gap by other mechanisms increases, and these new electrons create further avalanches. The other mechanisms are :

1.The positive ions liberated may have sufficient energy to cause liberation of electrons from the cathode when they impinge on it.

2. The excited atoms or molecules in avalanches may emit photons, and this will lead to the emission of electrons due to photo-emission.

3. The metastable particles may diffuse back causing electron emission.

The electrons produced by these processes are called secondary electrons. The

Following Townsend's procedure for current growth, let us assume

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$n_0' =$ number of secondary electrons produced due to secondary (γ) processes.

Let $n_0'' =$ total number of electrons leaving the cathode.

Then

$$n_0'' = n_0 + n_0 \tag{2.11}$$

The total number of electrons n reaching the anode becomes,

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

and

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

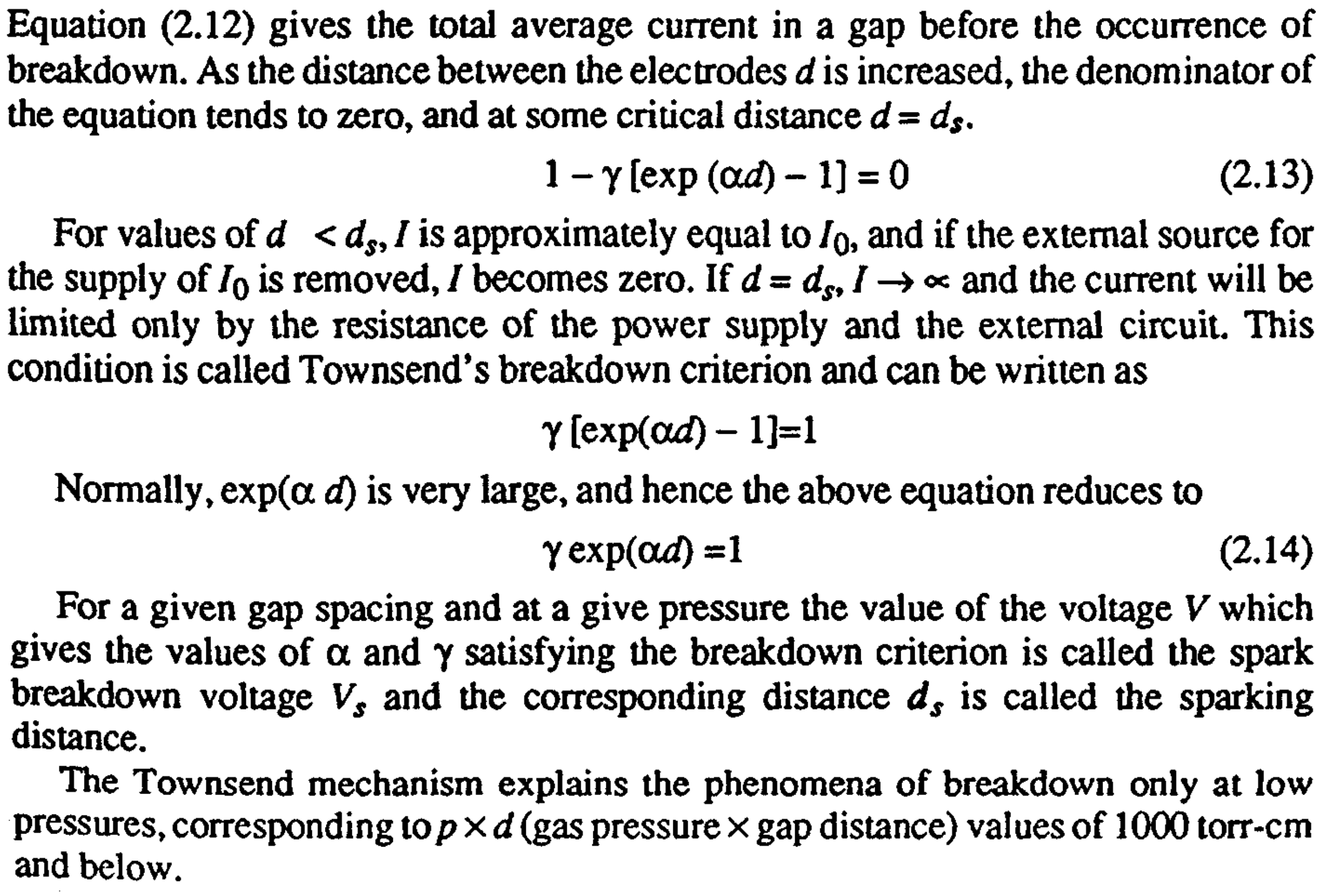
Eliminating n_0',

$$n = \frac{n_0 \exp(\alpha d)}{1 - \gamma[\exp(\alpha d) - 1]}$$

or

$$I = \frac{I_0 \exp(\alpha d)}{1 - \gamma[\exp(\alpha d) - 1]} \tag{2.12}$$

Townsend's Criterion For Breakdown:



Equation (2.12) gives the total average current in a gap before the occurrence of breakdown. As the distance between the electrodes d is increased, the denominator of the equation tends to zero, and at some critical distance $d = d_s$.

$$1 - \gamma\,[\exp(\alpha d) - 1] = 0 \tag{2.13}$$

For values of $d < d_s$, I is approximately equal to I_0, and if the external source for the supply of I_0 is removed, I becomes zero. If $d = d_s$, $I \rightarrow \propto$ and the current will be limited only by the resistance of the power supply and the external circuit. This condition is called Townsend's breakdown criterion and can be written as

$$\gamma\,[\exp(\alpha d) - 1] = 1$$

Normally, $\exp(\alpha\, d)$ is very large, and hence the above equation reduces to

$$\gamma \exp(\alpha d) = 1 \tag{2.14}$$

For a given gap spacing and at a give pressure the value of the voltage V which gives the values of α and γ satisfying the breakdown criterion is called the spark breakdown voltage V_s and the corresponding distance d_s is called the sparking distance.

The Townsend mechanism explains the phenomena of breakdown only at low pressures, corresponding to $p \times d$ (gas pressure × gap distance) values of 1000 torr-cm and below.

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**.

2a) State and explain Paschen's law.

→ 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 ~~to~~ 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

material of cathode

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

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

taking ln both sides:

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

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

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

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

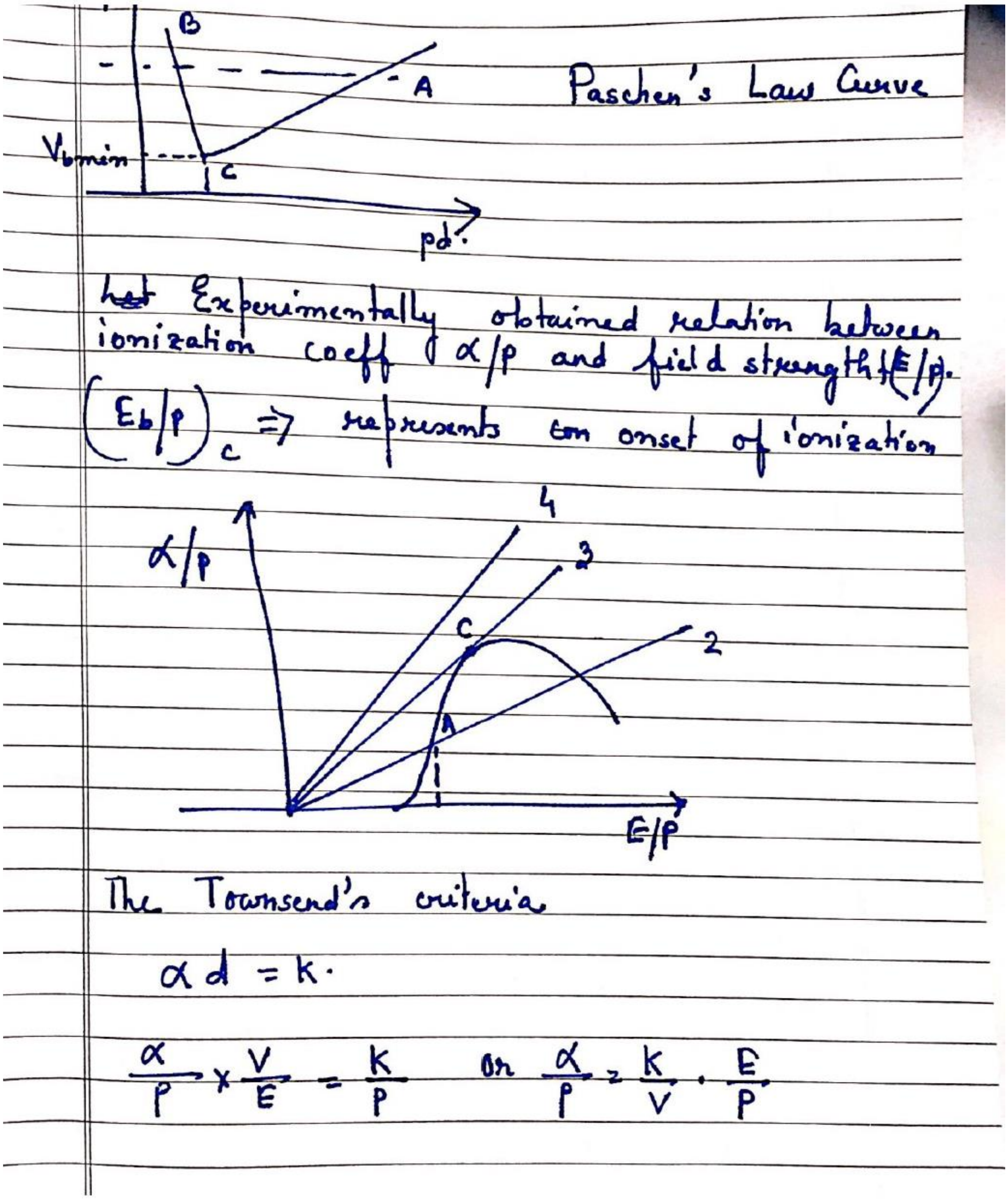
$$V_b = F(pd).$$

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 breakdo voltage is proportional to product pd, some region of the product pd the relation is linear.

2b) Derive the expression of minimum breakdown potential and corresponding pd(min).



Paschen's Law Curve

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

$(E_b/p)_c$ ⇒ represents ~~the~~ 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 ($E = V/d$) 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.

⇒ 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 on minimum sparking potential.

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

To explain the fact that there exist a minimum sparking potential in the relation between sparking potential and gap length assuming p to be constant can be explained by considering the η of ionization of electrons traversing the gap with different electron 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 ↑

In case of $(pd) < (pd)_{min}$, electrons cross the gap without making any collision and thus the sparking potential is higher.

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

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

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

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

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

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

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

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

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

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

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

In order to obtain minimum sparking potential

$$V_b = f(pd).$$

Taking logarithm in both sides.

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

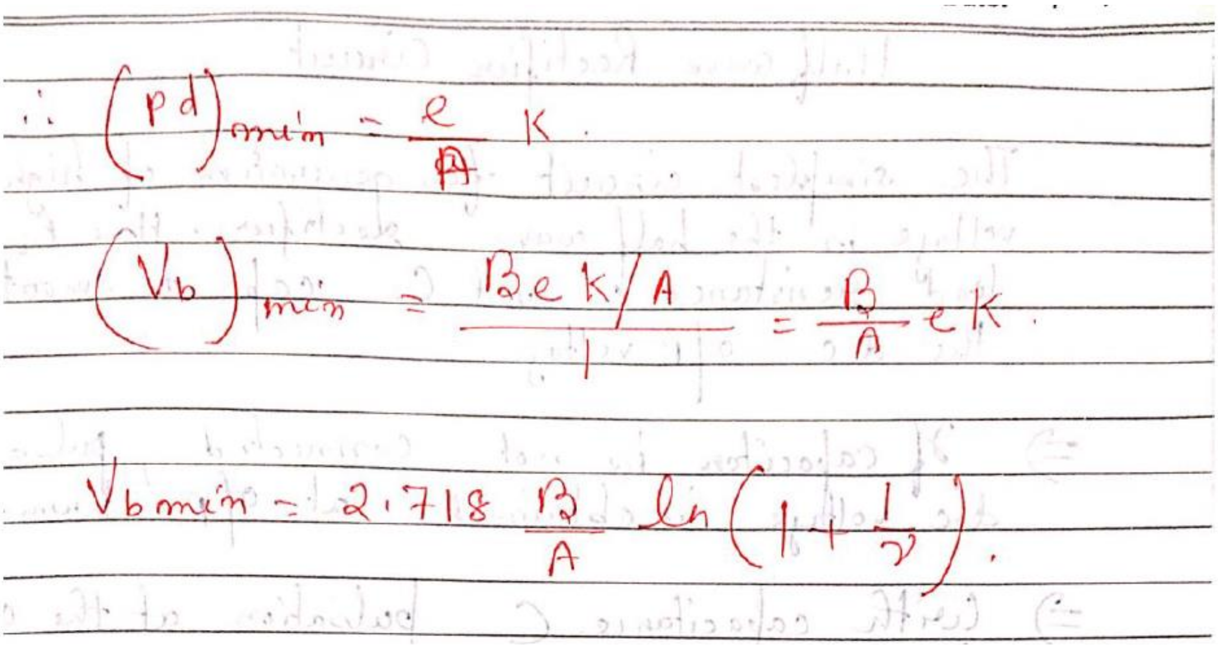
$$V_b = \frac{Bpd}{\ln \frac{Apd}{K}}.$$

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

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

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

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



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

$$\left(V_b\right)_{min} = \frac{Be K/A}{1} = \frac{B}{A} eK .$$

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

3a) Explain in detail the Streamer’s or Kanal mechanism of breakdown of gaseous insulating medium.

STREAMER OR KANAL MECHANISM OF SPARK

- The growth of charge carriers in an avalanche in a uniform field E0 = V0/d is described by the exponent $e^{\alpha d}$
- This is valid only as long as the electrical field of the space charges of electrons and ions can be neglected compared to the external field E0.
- In his studies of the effect of space charge of an avalanche on its own growth, Raether observed that when the charge concentration was higher than 106 but lower than 108 the growth of an avalanche was weakened.
- When the ion concentration exceeded 108 the avalanche current was followed by a steep rise in current and breakdown of the gap followed.

  Both slow growth at the lower concentration and rapid growth in the presence of the high concentration have been attributed to the modification of the originally uniform field E0 by the space charge field.

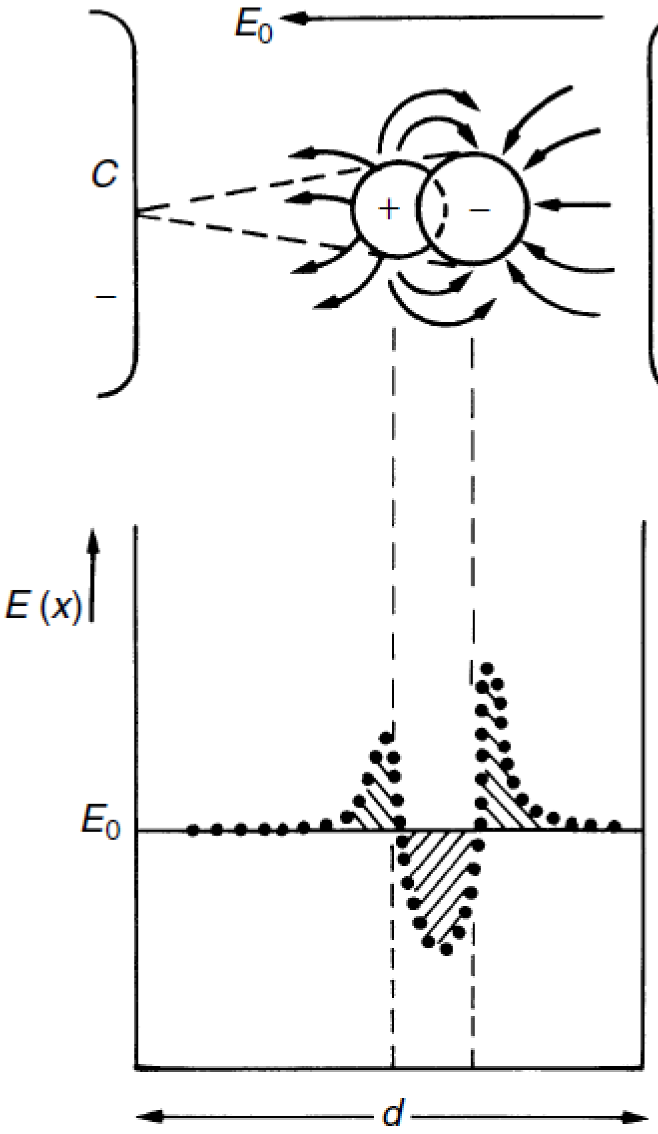


Figure shows diagrammatically the electric field around an avalanche as it progresses along the gap and the resulting modification to the original field E0.

- For simplicity the space charge at the head of the avalanche is assumed concentrated within a spherical volume, with the negative charge ahead because of the higher electron **mobility.**
- The field is enhanced in front of the head of the avalanche with field lines from the anode terminating at the head. Further back in the avalanche, the field between the electrons and the ions left behind reduced the applied field E0.

  Still further back the field between the cathode and the positive ions is enhanced again.

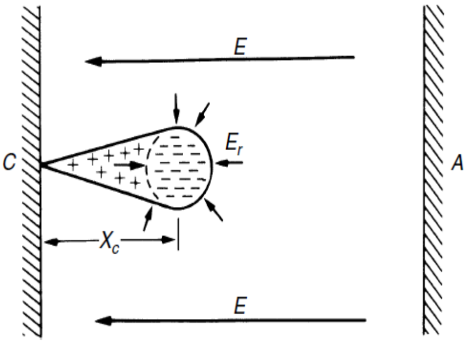
- The field distortion becomes noticeable with a carrier number n > 10^6. For instance, in nitrogen with d = 2 cm, p = 760 torr, the field distortion is about 1 per cent.
- If the distortion is 1% prevailed in the entire gap it would lead to a doubling of the avalanche size, but as the distortion is only significant in the immediate vicinity of the avalanche head it has still an insignificant effect.
- If the carrier number in the avalanche reaches $n \approx 10^8$ the space charge field becomes of the same magnitude as the applied field and may lead to the initiation of a streamer.

  The space charge fields play an important role in the mechanism of corona and spark discharges in nonuniform field gaps

- In the models developed by Raether and Meek it has been proposed that when the avalanche in the gap reaches a certain critical size the combined space charge field and externally applied field lead to intense ionization and excitation of the gas particles in front of the avalanche head.
- Instantaneous recombination between positive ions and electrons releases photons which in turn generate secondary electrons by the photoionization process. These electrons under the influence of the electric field in the gap develop into secondary avalanches as shown Since photons travel with the velocity of light, the process leads to a rapid development of conduction channel across the gap.
- On the basis of his experimental observations and some simple assumptions Raether developed an empirical expression for the streamer spark criterion of the form

$$\alpha x_c = 17.7 + \ln x_c + \ln \frac{E_r}{E}$$

- Er is the space charge field strength directed radially at the head of avalanche .
- E is the externally applied field strength.



Space charge field Er around avalanche head

- The resultant field strength in front of the avalanche is thus E +Er while in the positive ion region just behind the head the field is reduced to a value E - Er.
- It is also evident that the space charge increases with the avalanche length e(αx)
- The condition for the transition from avalanche to streamer assumes that space charge field Er approaches the externally applied field Er ≈E, hence the breakdown criterion becomes

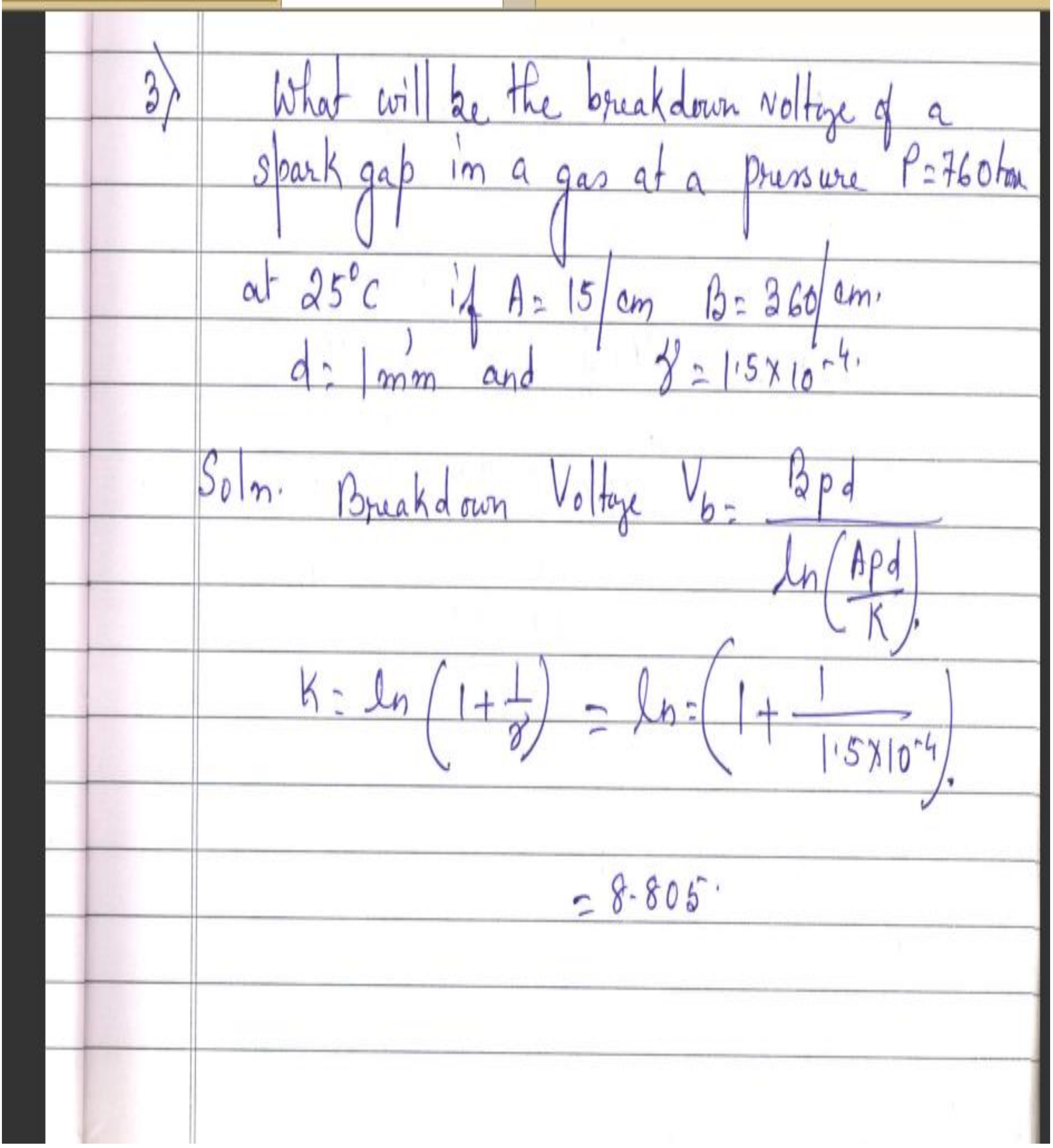
$$\alpha x_c = 17.7 + \ln x_c.$$

- The minimum breakdown value for a uniform field gap by streamer mechanism is obtained on the assumption that the transition from avalanche to streamer occurs when the avalanche has just crossed the gap d.
- Meek has shown that the radial field produced by positive ions immediately behind the head of the avalanche can be calculated from the expression

$$E_r = 5.3 \times 10^{-7} \frac{\alpha e^{\alpha x}}{\left(\frac{x}{p}\right)^{1/2}} \text{ volts/cm}$$

-
- where x is the distance (in cm) which the avalanche has progressed, p is the gas pressure in torr and α is the Townsend coefficient of ionization by electrons corresponding to the applied field E.

3B) What will be the breakdown voltage of a spark gap in a gas at a pressure of P = 760 torr at 25^0C if A = 15/cm, B = 360/cm, d = 1mm and $\gamma = 1.5 \times 10^-$



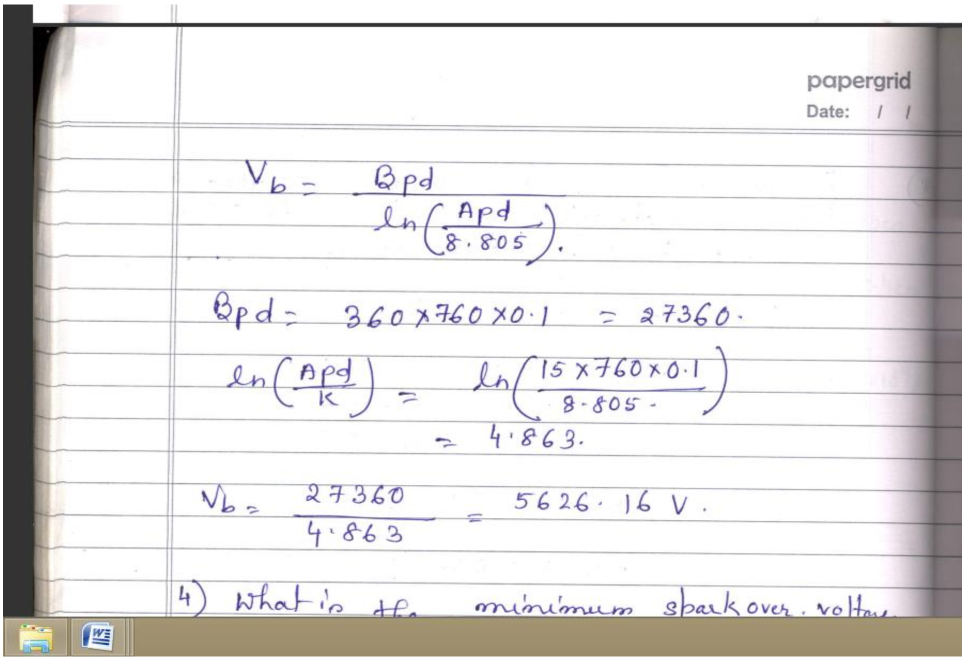
3) What will be the breakdown voltage of a spark gap im a gas at a pressure P=760torr at 25°C if A= 15/cm, B= 360/cm. d= 1mm and $\gamma = 1.5 \times 10^{-4}$.

Soln. Breakdown Voltage $V_b = \dfrac{Bpd}{\ln\left(\dfrac{Apd}{K}\right)}$.

$$K = \ln\left(1+\frac{1}{\gamma}\right) = \ln\left(1+\frac{1}{1.5\times10^{-4}}\right).$$

$$= 8.805.$$

4.



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$$V_b = \frac{Bpd}{\ln\left(\frac{Apd}{8.805}\right)}.$$

$$Bpd = 360 \times 760 \times 0.1 = 27360.$$

$$\ln\left(\frac{Apd}{K}\right) = \ln\left(\frac{15 \times 760 \times 0.1}{8.805}\right) = 4.863.$$

$$V_b = \frac{27360}{4.863} = 5626.16\ V.$$

4) What is the minimum sparkover voltage

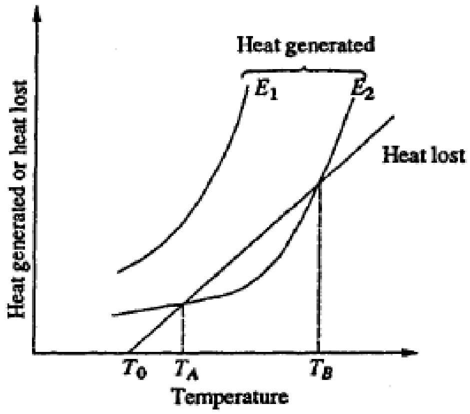
4. Discuss the following breakdown methods in solid dielectric:
(a) Thermal breakdown (b) Intrinsic breakdown , (c) Electromechanical breakdown

Breakdown of Solid Dielectric

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*
- where, б is the d.c. conductivity of the specimen.
- $$W_{d.c.} = E^2\sigma \quad \text{W/cm}^3$$
- Under a.c. fields, the heat generated
- where, *f*= frequency in Hz,
- δ= loss angle of the dielectric material, and *E- rms value.*

- The heat dissipated *(W_T)is given by*
- $W_T = C_V \frac{dT}{dt} + \text{div}\,(K \text{ grad } T)$
- 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 E1 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.



B) **INTRINSIC BREAKDOWN**

- When voltages are applied only for short durations of the order of 10-8S the dielectric strength of a solid dielectric increases very rapidly to an upper limit called the intrinsic electric strength.
- Experimentally, this highest dielectric strength can be obtained only under the best experimental conditions when all extraneous influences have been isolated and the value depends only on the structure of the material and the temperature.
- Intrinsic breakdown depends upon the presence of free electrons which are capable of migration through the lattice of the dielectric.
- Usually, a small number of conduction elections are present in solid dielectrics, along with some structural imperfections and small amounts of impurities.
- The impurity atoms, or molecules or both act as traps for the conduction electrons up to certain ranges of electric fields and temperatures.
- When these ranges are exceeded, additional electrons in addition to trapped electrons are released, and these electrons participate in the conduction process.
- Based on this principle, two types of intrinsic breakdown mechanisms have been proposed.
- **Electronic Breakdown**
- intrinsic breakdown occurs in time of the order of 10~8s
- It is assumed to be electronic in nature.
- The initial density of conduction (free) electrons is also assumed to be large, and electron-electron collisions occur.
- When an electric field is applied, electrons gain energy from the electric field and cross the forbidden energy gap from the valency to the conduction band.
- When this process is repeated, more and more electrons become available in the conduction band, eventually leading to breakdown.
- iii) **Avalanche or Streamer Breakdown**
- This is similar to breakdown in gases due to cumulative ionization. Conduction electrons gain sufficient energy above a certain critical electric field and cause liberation of electrons from the lattice atoms by collisions.
- Under uniform field conditions, if the electrodes are embedded in the specimen, breakdown will occur when an electron avalanche bridges the electrode gap.
- An electron within the dielectric, starting from the cathode will drift towards the anode and during this motion gains energy from the field and loses it during collisions.
- When the energy gained by an electron exceeds the lattice ionization potential, an additional electron will be liberated due to collision of the first electron.

- This process repeats itself resulting in the formation of an electron avalanche.
- Breakdown will occur, when the avalanche exceeds a certain critical size.
- In practice, breakdown does not occur by the formation of a single avalanche itself, but occurs as a result of many avalanches formed within the dielectric and extending step by step through the entire thickness of the material

C) **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 *d0 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 above 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. Write short notes on different types of secondary ionization.

Secondary Ionization Processes

Secondary ionization processes by which secondary electrons are produced are the one which sustain a discharge after it is established due to ioniszation by collision and photo-ionization

(a) *Electron Emission due to Positive Ion Impact*

- **Positive ions are formed due to ionization by collision or by photo-ionization, and being positively charged, they travel towards the cathode.**
- **A positive ion approaching a metallic cathode can cause emission of electrons from the cathode by giving up its kinetic energy on impact.**
- **If the total energy of the positive ion, namely, the sum of its kinetic energy and the ionization energy, is greater than twice the work function of the metal, then one electron will be ejected and a second electron will neutralize the ion.**
- **The probability of this process is measured as γ which is called the Townsend's secondary ionization coefficient due to positive ions and is defined as the net yield of electrons per incident positive ion.**

γ increases with ion velocity and depends on the kind of gas and electrode material used

(b) Electron Emission due to Photons

- **To cause an electron to escape from a metal, it should be given enough energy to overcome the surface potential barrier.**
- **The energy can also be supplied in the form of a photon of ultraviolet light of suitable frequency.**
- **Electron emission from a metal surface occurs at the critical condition.**

$$h.v \geq \varphi$$

- **Where ϕ is the work function of the metallic electrode.**

$$v = \frac{\varphi}{h}$$

- **The frequency (v) is given by the relationship**
- **If the incident radiation has a greater frequency than the threshold frequency, then the excess energy goes partly as the kinetic energy of the emitted electron and partly to heat the surface of the electrode.**

- **Since ϕis typically a few electron volts, the threshold frequency lies in the far ultra-violet region of the electromagnetic radiation spectrum.**

(c) Electron Emission due to Metastable and Neutral Atoms

- **A metastable atom or molecule is an excited particle whose lifetime is very large compared to the lifetime of an ordinary particle (10~8s).**
- **Electrons can be ejected from the metal surface by the impact of excited (metastable) atoms, provided that their total energy is sufficient to overcome the work function.**
- **This process is most easily observed with metastable atoms, because the lifetime of other excited states is too short for them to reach the cathode and cause electron emission, unless they originate very near to the cathode surface.**
- **the yields can also be large nearly 100%, for the interactions of excited *He atom with a clean surface of molybdenum,* nickel or magnesium.**
- **Neutral atoms in the ground state also give rise to secondary electron emission if their kinetic energy is high (= 1000 eV).**
- **At low energies the yield is considerably less.**

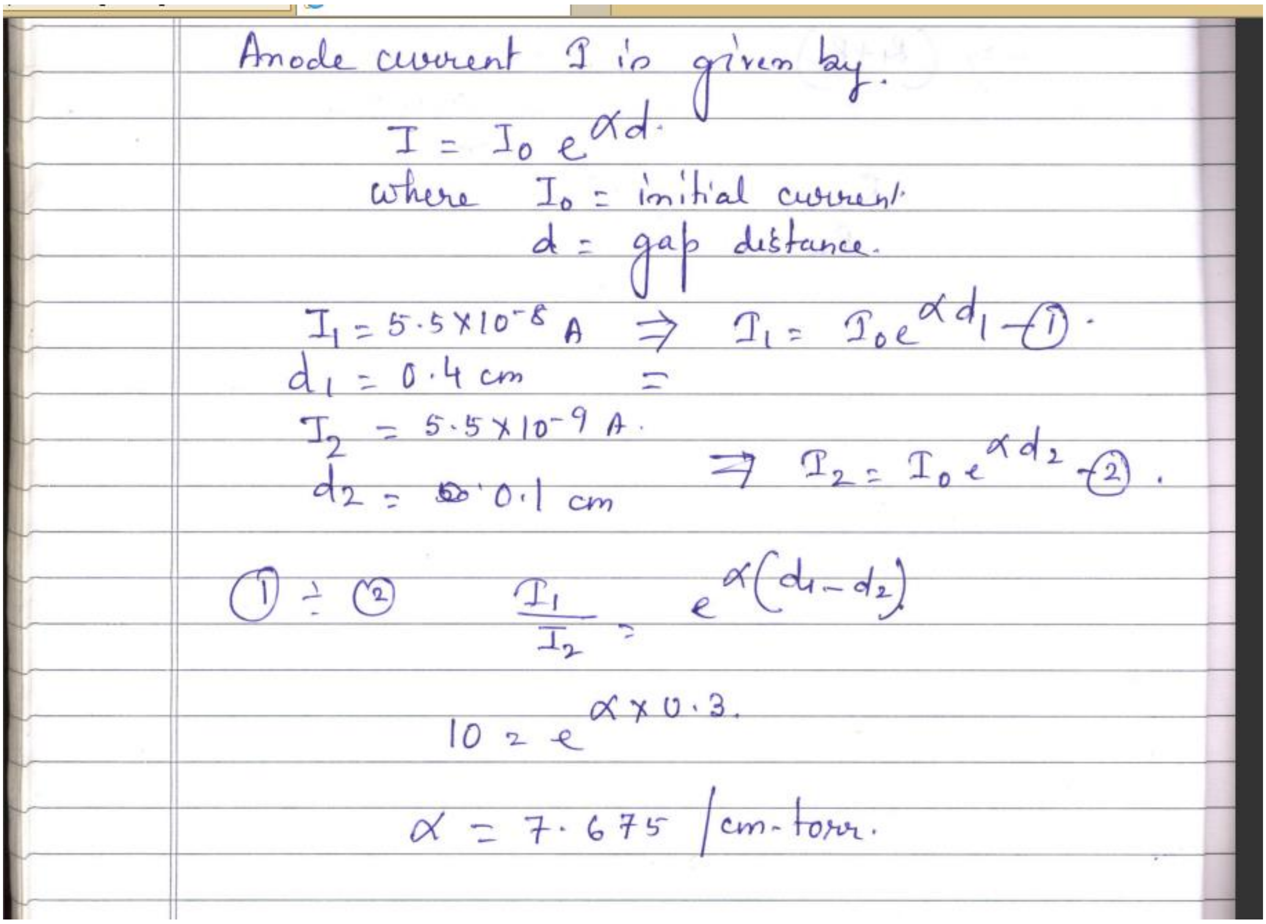
6a) What is time-lag? Discuss its components and the factors which affect these components.

TIME LAGS FOR BREAKDOWN

- The mechanism of spark breakdown is considered as a function of ionization processes under uniform field conditions.
- in practical engineering designs, the breakdown due to rapidly changing voltages or impulse voltages is of great importance.
- 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.

6b) In an experiment in a certain gas, it was found that the steady state current is 5.5 x 10^{-8} A at 8 kV at a distance of 0.4 cm between the plane electrodes. Keeping the field constant and reducing the distance to 0.1 cm results in a current of 5.5 x 10^{-9} A. Calculate Townsend's primary ionization coefficient α.



Anode current I is given by.

$I = I_0 e^{\alpha d}$.

where I_0 = initial current.

d = gap distance.

$I_1 = 5.5 \times 10^{-8}$ A $\Rightarrow I_1 = I_0 e^{\alpha d_1}$ — ①.

$d_1 = 0.4$ cm

$I_2 = 5.5 \times 10^{-9}$ A.

$d_2 = 0.1$ cm $\Rightarrow I_2 = I_0 e^{\alpha d_2}$ — ②.

① ÷ ② $\frac{I_1}{I_2} = e^{\alpha(d_1 - d_2)}$

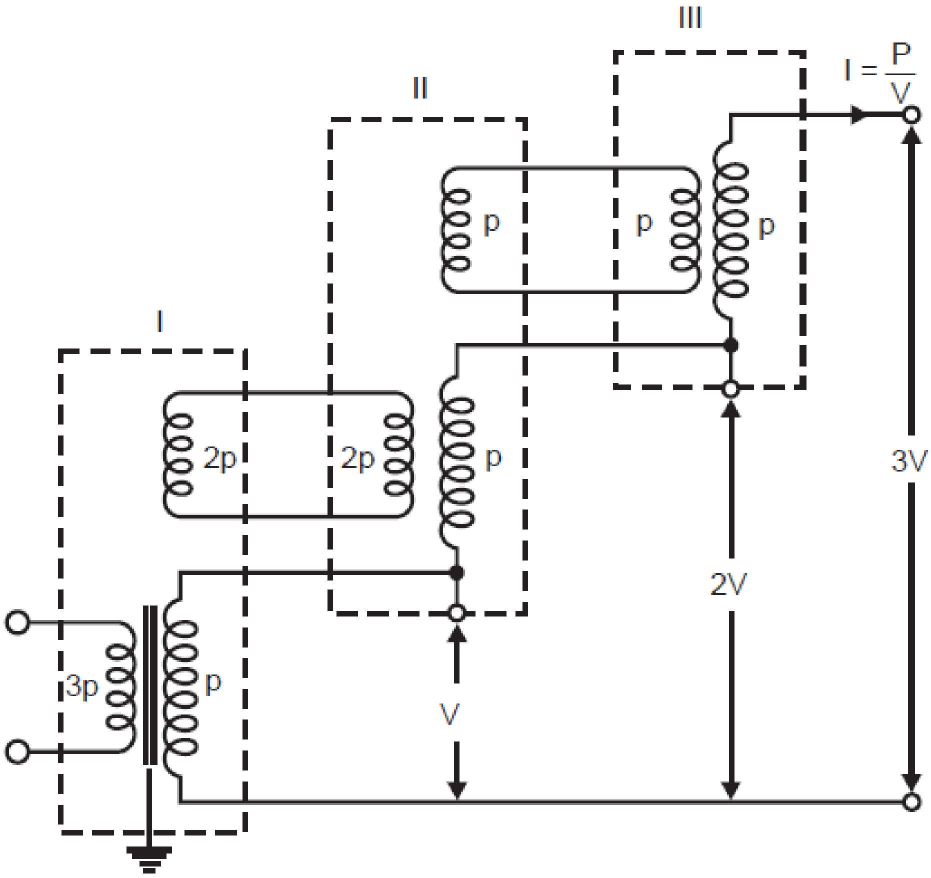
$10 = e^{\alpha \times 0.3}$.

$\alpha = 7.675$ /cm-torr.

7. What is a cascaded transformer? Explain why cascading is done? Describe with neat diagram a three stage cascaded transformer. Label the power ratings of various stages of the transformer.

Figure shows a basic scheme for cascading three transformers. The primary of the first stage transformer is connected to a low voltage supply. A voltage is available across the secondary of this transformer. The tertiary winding (excitation winding) of first stage has the same number of turns as the primary winding, and feeds the primary of the second stage transformer. The potential of the tertiary is fixed to the potential *V* of the secondary winding as shown in Fig. 2.9. The secondary winding of the second stage transformer is connected in series with the secondary winding of the first stage transformer, so that a voltage of 2*V* is available between the ground and the terminal of secondary of the second stage transformer. Similarly, the stage-III transformer is connected in series with the second stage transformer. With this the output voltage between ground and the third stage transformer, secondary is 3*V*. it is to be noted that the individual stages except the upper most must have three-winding transformers. The upper most, however, will be a two winding transformer.

Fig shows metal tank construction of transformers and the secondary winding is not divided. Here the low voltage terminal of the secondary winding is connected to the tank. The tank of stage-I transformer is earthed. The tanks of stage-II and stage-III transformers have potentials of *V* and 2*V*, respectively above earth and, therefore, these must be insulated from the earth with suitable solid insulation. Through h.t. bushings, the leads from the tertiary winding and the h.v. winding are brought out to be connected to the next stage transformer.



The main disadvantage of cascading the transformers is that the lower stages of the primaries of the transformers are loaded more as compared with the upper stages.

The loading of various windings is indicated by *P* in Fig. 2.9. For the three-stage transformer, the total output *VA* will be 3*VI* = 3*P* and, therefore, each of the secondary winding of the transformer would carry a current of *I* = *P*/*V*. The primary winding of stage-III transformer is loaded with *P* and so also the tertiary winding of second stage transformer. Therefore, the primary of the second stage transformer would be loaded with $2P$. Extending the same logic, it is found that the first stage primary would be loaded with P. Therefore, while designing the primaries and tertiaries of these transformers, this factor must be taken into consideration.