CMR INSTITUTE OF TECHNOLOGY	USN											

Internal Assesment Test I – November 2021

Sub:	HIGH VOLTAGE ENGINEERING							Code:	17EE73
Date:	13.11.2021	Duration:	90 mins	Max Marks:	50	Sem:	7	Section:	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)	Write short notes on breakdown of electronegative gases.	[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	Explain the following methods of breakdown of liquid dielectrics, (i) Suspended particle theory; (ii) Stressed oil volume theory; (iii) Cavitation Theory.	[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

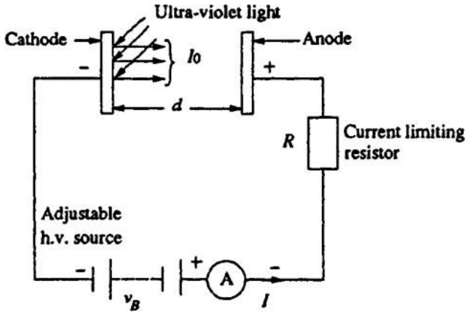


Fig. 2.1 Arrangement for study of a Townsend discharge

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., $\gamma = \gamma_1 + \gamma_2 + \gamma_3 = \gamma$ 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 :

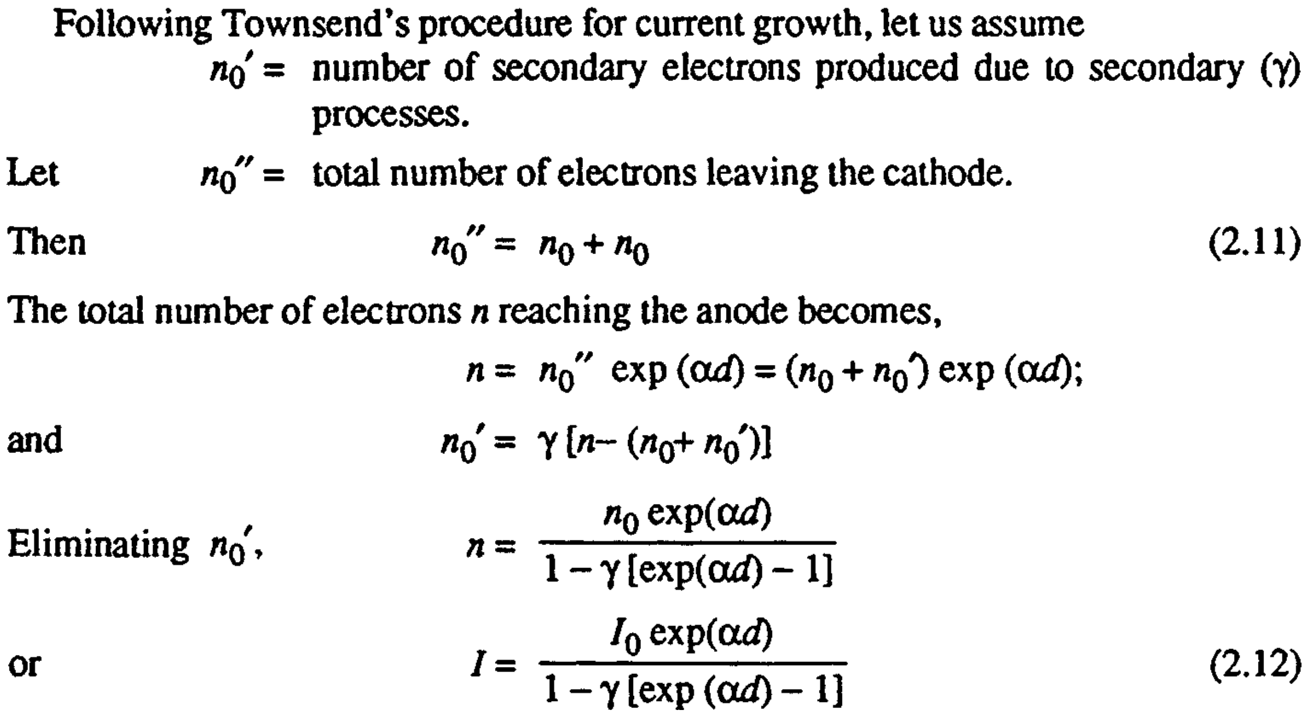
1. The positive ions liberated may have sufficient energy to cause liberation of electrons from the cathode when they impinge on it.

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



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

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 ~~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 by the ionization coefficient α/p as a function of field strength E and gas pressure p

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

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

taking ln both sides:

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

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

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

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

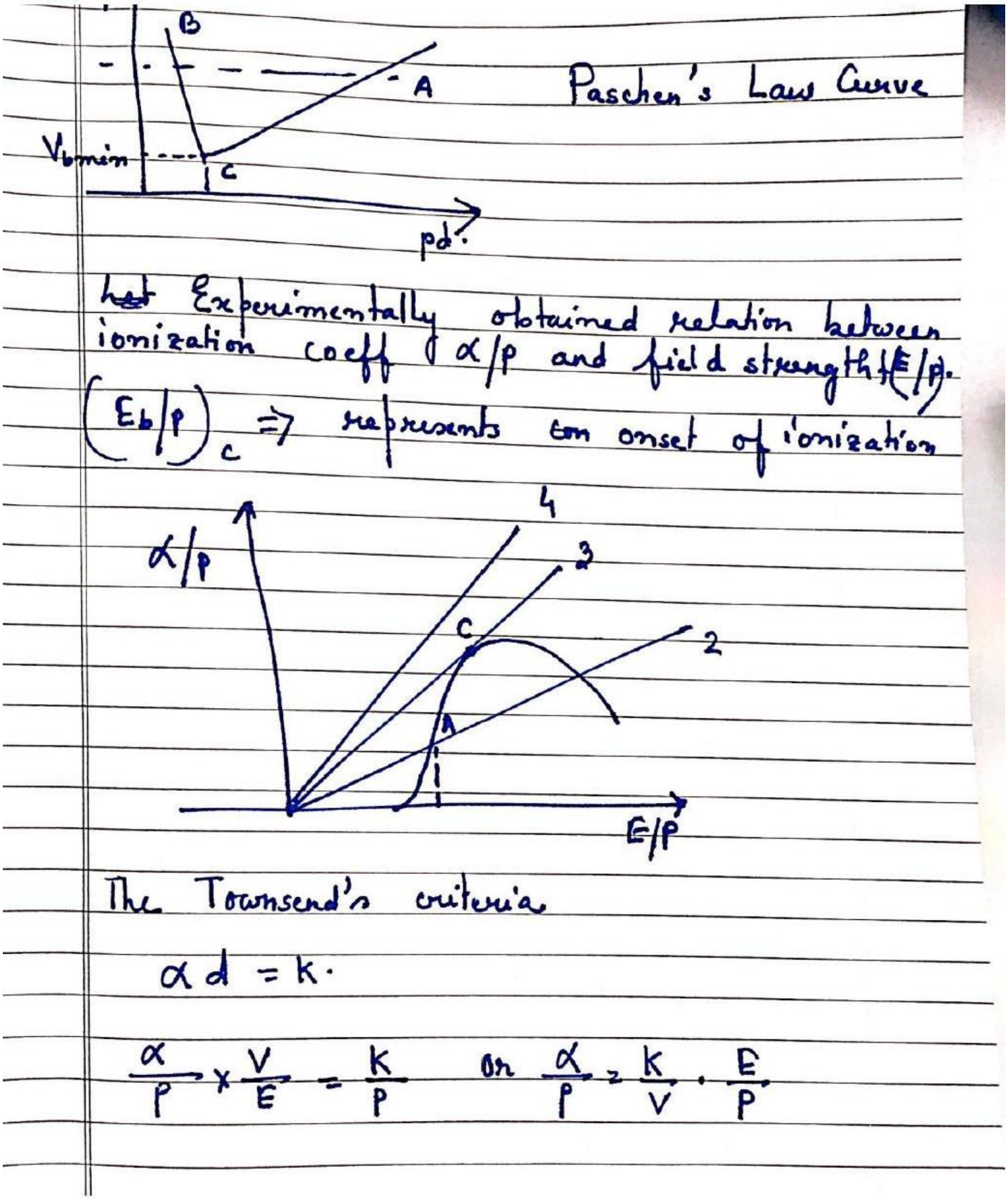
$$V_b = F(pd).$$

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).

$(E_b/p)_c \Rightarrow$ 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 ($E = V/d$) 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 points A, B, C are shown in previous figure.

To explain the fact that there exists a minimum sparking potential in the relation between sparking potential and gap length 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 ~~to~~ 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 $\gamma =$ constant

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

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

In order to obtain minimum sparking potential

$$V_b = f(pd).$$

Taking logarithm in both sides.

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

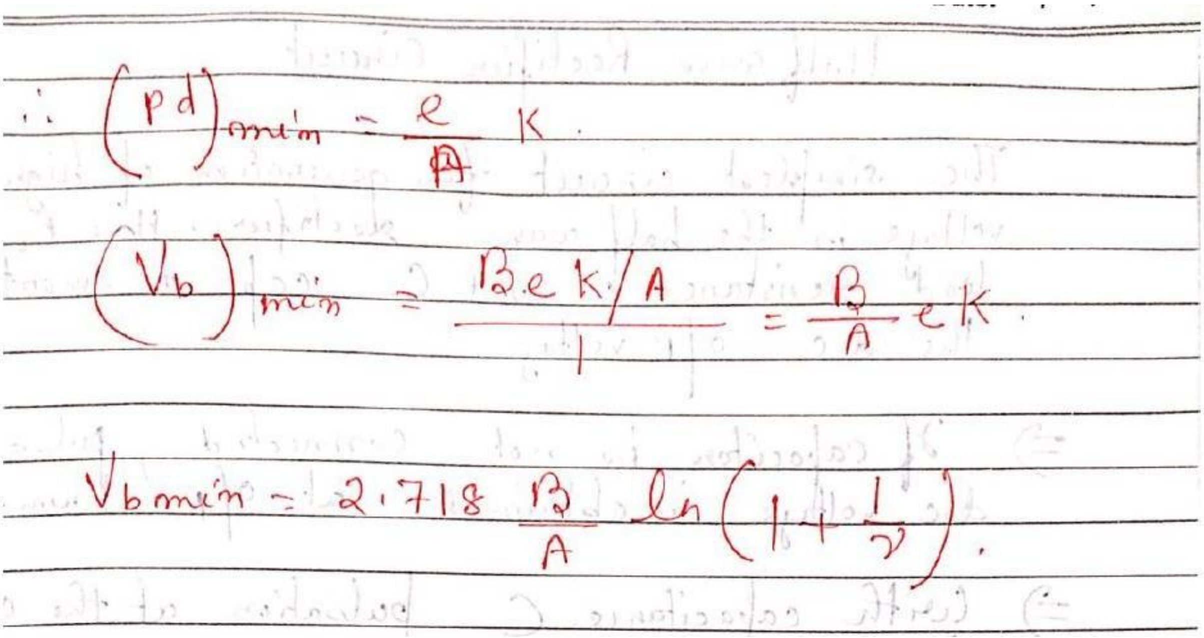
$$V_b = \frac{Bpd}{\ln \frac{Apd}{K}}.$$

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

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

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

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



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

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

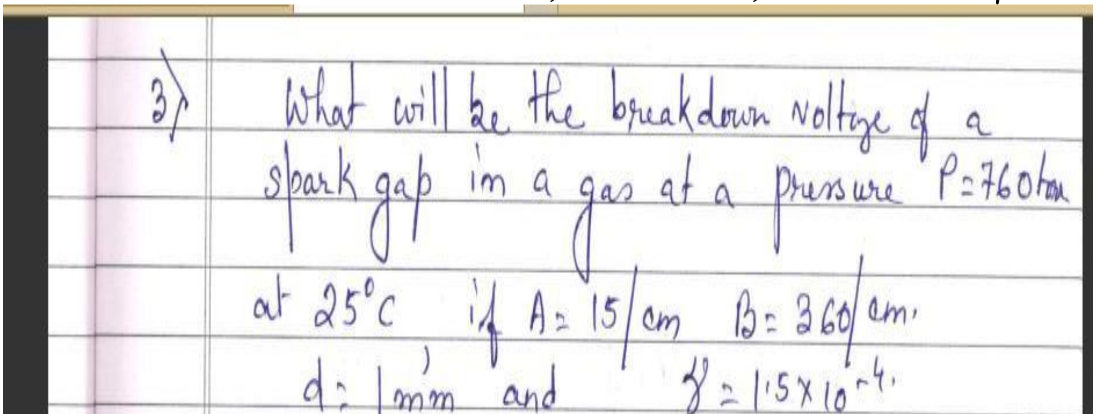
$$V_{b\,min} = 2.718 \frac{B}{A} \ln\left(1 + \frac{1}{\gamma}\right) .$$

3a) Breakdown in Electronegative gases

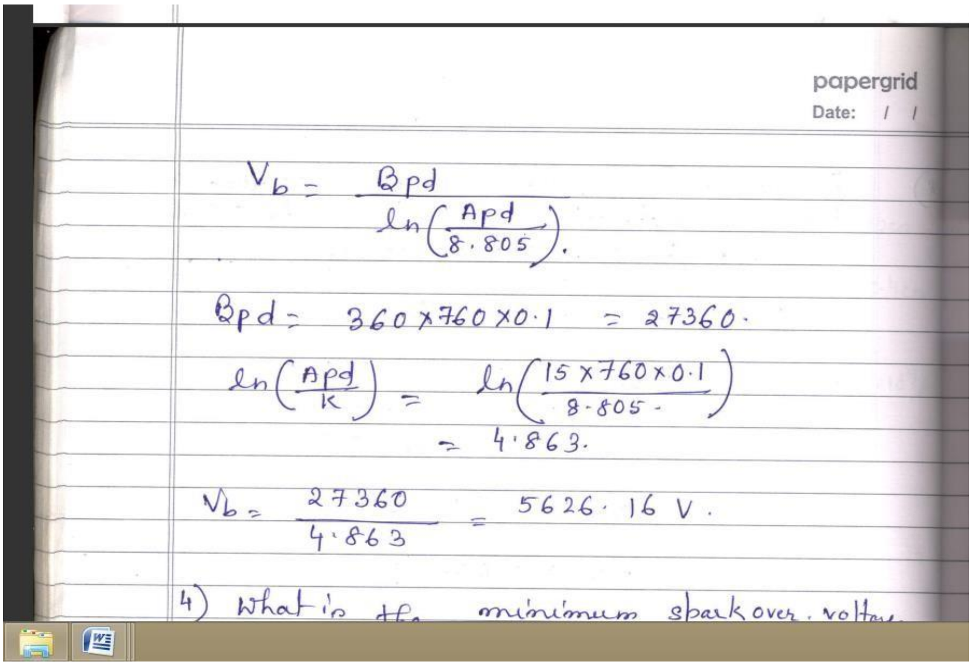
- The types of collisions in which electrons may become attached to atoms or molecules to form negative ions are called attachment collisions.
- Electron attachment process depends on the energy of the electron and the nature of the gas and is a very important process from the engineering point of view.
- All electrically insulating gases, such as CO_2, Cl_2, F_2, C_2F_6, C_3F_8, C_4F_{10}, CCl_2F_2, and SF_6 exhibit this property.
- An electron attachment process can be represented as:

  Atom + e~+ k -------» negative atomic ion + (Ea + K)
- The energy liberated as a result of this process is the kinetic energy K plus the electron affinity Ea.
- In the attaching or insulating gases, the atoms or molecules have vacancies in their outermost shells and, therefore, have an affinity for electrons.
- The attachment process plays a very important role in the removal of free electrons from an ionized gas when arc interruption occurs in gas-insulated switchgear.

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 in a gas at a pressure P=760 torr at 25°C if A= 15/cm B= 360/cm, d= 1mm and $\gamma = 1.5 \times 10^{-4}$.



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

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

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

$$= 4.863.$$

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

4) What is the minimum spark over voltage

4. Discuss the following breakdown methods in liquid dielectric:

Several theories have been proposed to explain the breakdown in liquids :

(a) Electronic Breakdown

(b) Suspended Particle Mechanism

(c) Cavitations and Bubble Mechanism

(d) Stressed Oil Volume Mechanism

Suspended particle theory

- In commercial liquids, the presence of solid impurities cannot be avoided.
- These impurities will be present as fibrous or as dispersed solid particles.
- The permittivity of these particles (**$\varepsilon 1$**) will be different from the permittivity of the liquid (**$\varepsilon 2$**).
- 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

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

- 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 $\varepsilon 1$ is the permittivity of gas bubbles.
- The force given above increases as the permittivity of the suspended particles ($\varepsilon 1$) 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 $\varepsilon_1 \rightarrow \infty$

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

- 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)
- **$F_v = 6\pi n r v$**
- where η is the viscosity of liquid, r the radius 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

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

- Here 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,

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

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

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

Cavitation and the bubble theory

- It is experimentally observed that in many liquids, the breakdown strength depends strongly on the applied **hydrostatic pressure.**
- **Hydrostatic pressure** is the pressure that is exerted by a fluid at equilibrium at a given point within the fluid, due to the force of gravity

- 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.

Stressed oil volume theory

- In commercial liquids where minute traces of impurities are present, breakdown strength is determined by the **"largest possible impurity"** or "**weak link"**.
- **On a statistical basis** it was proposed that electrical breakdown strength of oil is defined by the weakest region in the oil, the region which is **stressed to maximum** and by the **volume of oil included** in that region.
- In non-uniform fields, the stressed oil volume is taken as the volume which is contained between the **maximum stress (Emax) contour and 0.9 Emax contour**.
- According to this theory the breakdown strength is inversely proportional to the stressed oil volume.

- The **breakdown voltage** is highly **influenced** by the **gas content** in the oil, the **viscosity** of the oil, and **the presence of other impurities.**
- These being uniformly distributed, increase in the stressed oil volume consequently results in a reduction in the breakdown voltage.

⦿ The variation of the Breakdown voltage stress with the Stressed oil volume is shown in Fig.

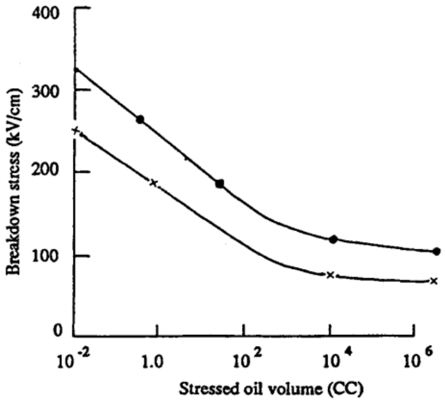


Fig. 3.7 Power frequency (50 Hz) a.c. breakdown stress as a function of the stressed oil volume
- ● With steady voltage rise
- × One minute withstand voltage

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.

- **Where ϕ is the work function of the metallic electrode.** $h.v \geq \varphi$

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

- **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.

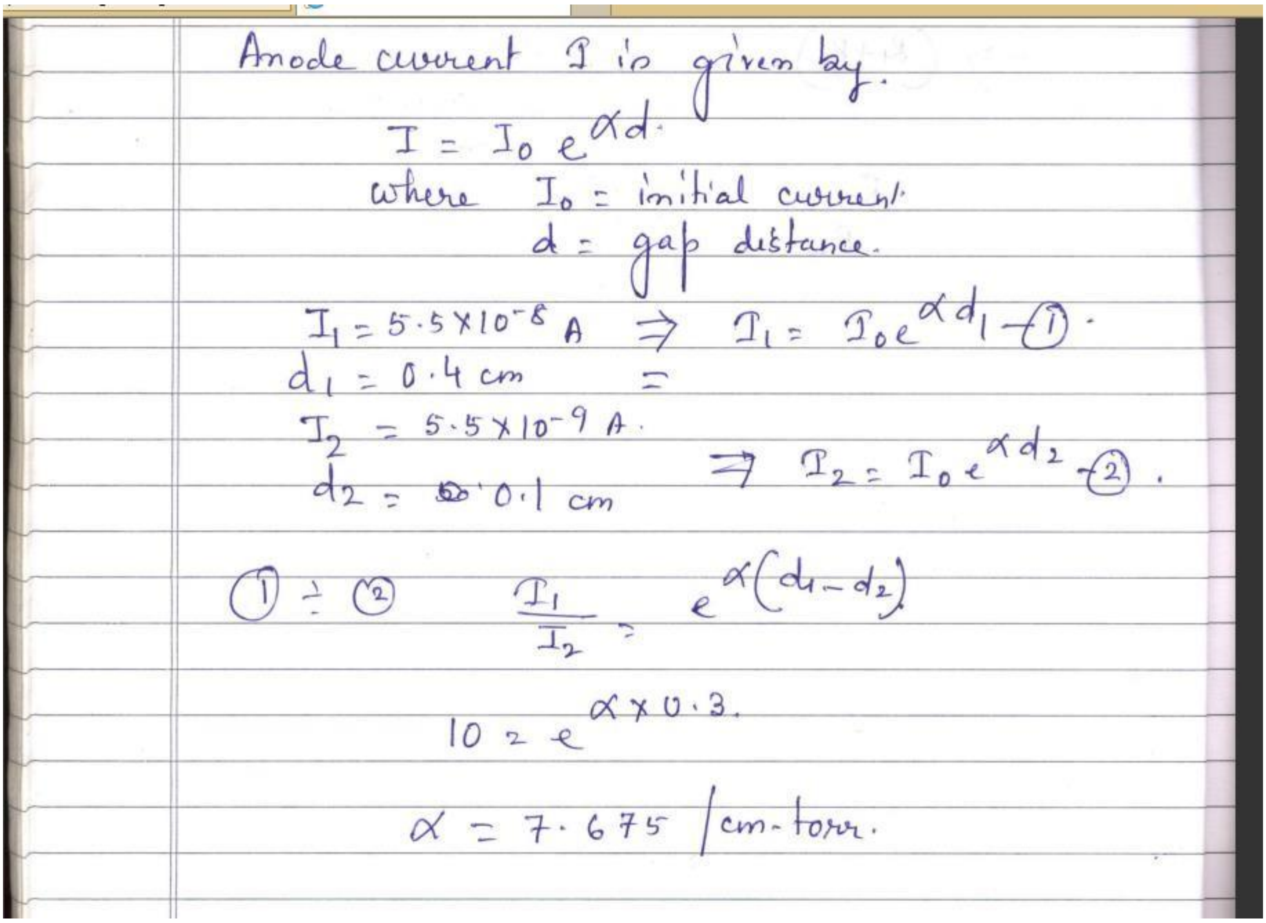
TIME LAGS FOR BREAKDOWN

- 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.

$I_1 = 5.5\times10^{-8}$ A $\Rightarrow$ $I_1 = I_0 e^{\alpha d_1}$ — ①.

$d_1 = 0.4$ cm =

$I_2 = 5.5\times10^{-9}$ A.

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

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

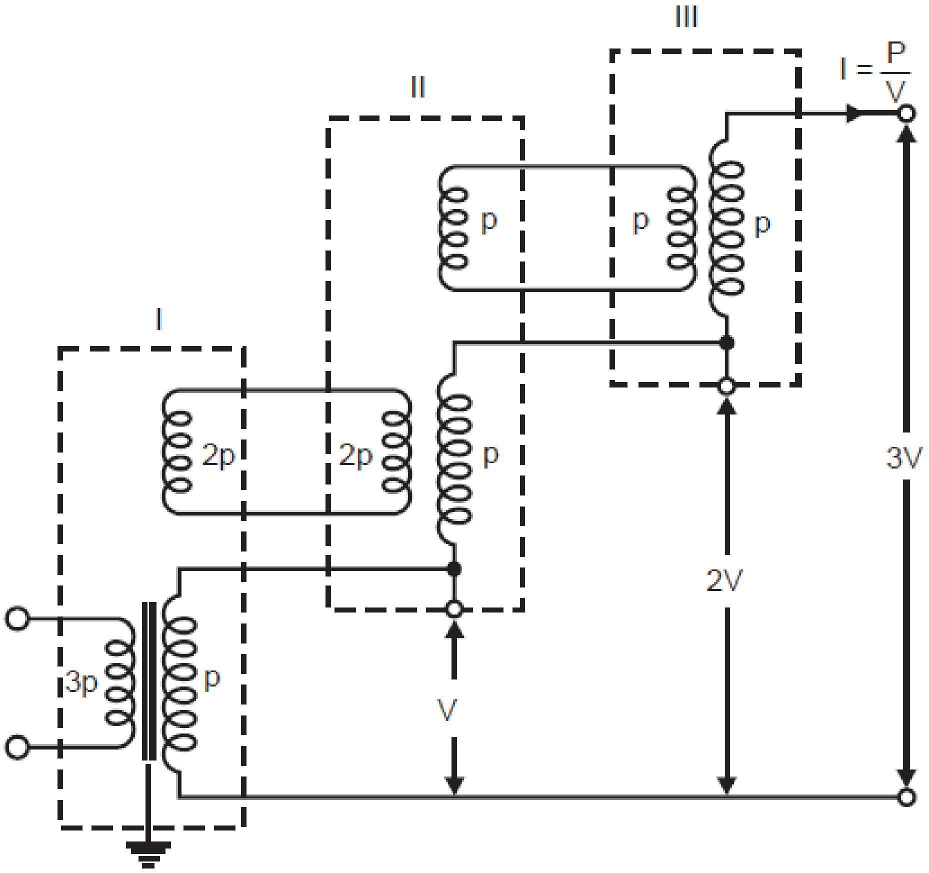
$10 = e^{\alpha \times 0.3}$.

$\alpha = 7.675$ /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 $2V$ 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 $3V$. 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 $2V$, 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 $3VI = 3P$ 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.