CMR
INSTITUTE OF
TECHNOLOGY

USN

Internal Test 5 –February 2022

Sub:	High Voltage Engineering							Code:	17EE73
Date:	09/02/2022	Duration:	90 mins	Max Marks:	50	Sem:	**7 B**	Branch:	EEE

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

		Marks	OBE CO	OBE RBT
1.	Define impulse wave. Discuss how impulse wave is generated in laboratory with a neat diagram of Marx generator.	[2+3+5]	CO3	L2

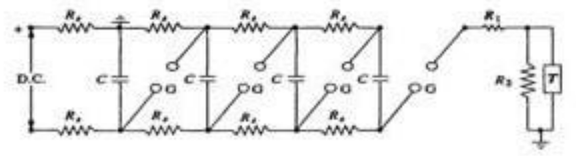
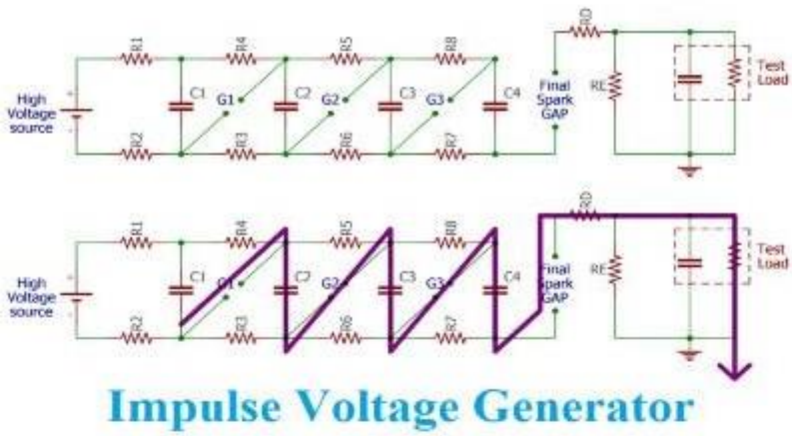


Fig. 6.17a Schematic diagram of Marx circuit arrangement for multistage impulse generator

C — Capacitance of the generator
R_s — Charging resistors
G — Spark gap
R_1, R_2 — Wave shaping resistors
T — Test object



- The schematic diagram of Marx circuit and its modification are shown in Figs. 6.17a and 6.17b, respectively.
- Usually the charging resistance is chosen to limit the charging current to about 50 to 100 mA, and the generator capacitance C is chosen such that the product CRs is about 10 s to 1 min.
- The gap spacing is chosen such that the breakdown voltage of the gap G is greater than the charging voltage V.
- All the capacitances are charged to the voltage V in about 1 minute.
- When the impulse generator is to be discharged, the gaps G are made to spark over simultaneously by some external means.
- All the capacitors C get connected in series and discharge into the load capacitance or the test object

- The generator capacitance **C1** is to be first charged and then discharged into the wave shaping circuits.
- A single capacitor **C1** may be used for voltages up to 200 kV.
- Beyond this voltage, a single capacitor and its charging unit may be too costly, size becomes very large.
- The cost and size of the impulse generator increases at a rate of the **square or cube** of the **voltage rating**.
- Producing very **high voltages**, a bank of capacitors are **charged in parallel** and then **discharged in series**.
- The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by **Marx**.
- **Modified Marx circuits** are used for the multistage impulse generators.

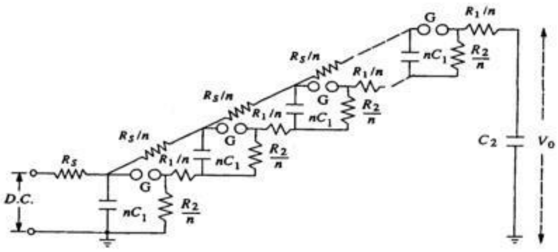


Fig. 6.17b Multistage impulse generator incorporating the series and wave tail resistances within the generator

- The discharge time constant CR1/n (for n stages) will be very very small (microseconds), compared to the charging time constant CRs which will be few seconds.
- Hence, no discharge takes place through the charging resistors Rs.
- In the Marx circuit is of Fig. 6.17a the impulse wave shaping circuit is connected externally to the capacitor unit In Fig. b,
- The modified Marx circuit is shown, wherein the resistances R1 and R2 are incorporated inside the unit.

---------------------------------(10 Marks)

2.	Define Townsend's first and second ionization coefficients. Explain the Townsends criterion for a spark. Discuss the limitations of Townsend's theory.	[3+4+3]	CO1	L2

Townsend's Theorem

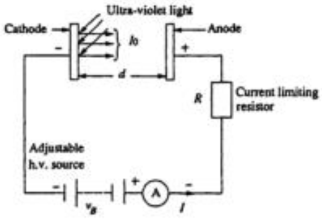


Fig. 2.1 Arrangement for study of a Townsend discharge

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.*

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.

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 $$x = 0, n_x = n_0 \quad (2.6)$$

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

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

$$n_d = n_0 \exp(\alpha d) \quad (2.8)$$

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

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

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

$$I = I_0 \exp(\alpha d) \quad (2.10)$$

where I_0 is the initial current at the cathode.

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 $$n_0'' = n_0 + n_0 \quad (2.11)$$

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

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 $d = d_s$.

$$1 - \gamma [\exp(\alpha d) - 1] = 0 \qquad (2.13)$$

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 $d = d_s$, $I \rightarrow \infty$ 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

$$\gamma \exp(\alpha d) = 1 \qquad (2.14)$$

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**.

3.	Explain the following methods of breakdown of liquid dielectrics, (i) suspended particle theory; (ii) stressed oil volume theory; (iii) Cavitation Theory.	[4+4+3]	CO1	L2

i)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 (**ε1**) will be different from the permittivity of the liquid (**ε2**).
- 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 ε1 > ε2 and towards a place of lower stress if ε1 < ε2 when ε1 is the permittivity of gas bubbles.
- The force given above increases as the permittivity of the suspended particles (ε1) increases. If ε1 → ∞

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

Let $\varepsilon_1 \to \infty$

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

- 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)
- **Fv= 6πηrv**
- 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

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

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

- Where σ 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.

iii) **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.

iii) 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**:

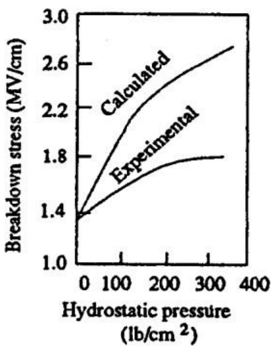
- *(a)* **Gas pockets at the surfaces of the electrodes;**
- *(b)* **electrostatic repulsive forces between space charges which may be sufficient to overcome the surface tension**;
- (c) **gaseous products due to the dissociation of liquid molecules by electron collisions**
- *(d)* **vaporizations of 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 σ is the surface tension of the liquid,
- ε_1 is the permittivity of the liquid,
- ε_2 is the permittivity of the gas bubble,
- r is the initial radius of the bubble assumed as a sphere
- V_b 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



4.	State and explain Paschen's law. Derive the expression of minimum breakdown potential and corresponding **pd**(min).	[5+5]	CO1	L2

→ Townsend's Criterion.

$\gamma\left[\exp(\alpha d) - 1\right]$ enables the evaluation of breakdown voltage of the gap by the use of appropriate values of α/p and γ 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/p 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 $E = \frac{V_b}{d}$.

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

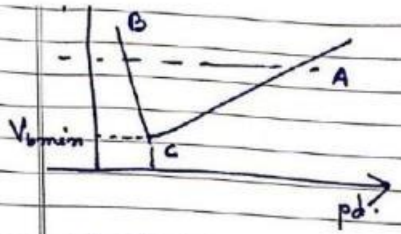
$$\therefore f\left(\frac{V_b}{pd}\right) = \frac{K}{pd}.$$

$$V_b = F(pd).$$

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

→ Paschen's Law.

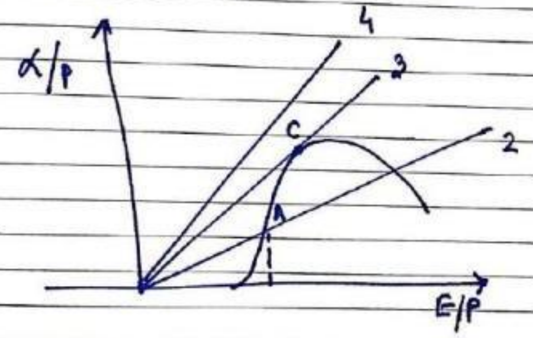
→ this relation does not mean that breakdown voltage is proportional to product pd, some region of the product pd the relation is linear.



Paschen's Law Curve

~~het~~ 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 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.

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 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 $V \uparrow$

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.

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.

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

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

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

	⇒ Analytical expression for minimum sparking potential can be obtained using general expression for α/p. $$\frac{\alpha}{p} = Ae^{-Bp/E}$$ $$\therefore \alpha = pAe^{-Bp/E}$$ $$\alpha = pAe^{-Bpd/V_b}$$ $$e^{Bpd/V_b} = \frac{pA}{\alpha}$$ $$\therefore \frac{1}{\alpha} = \frac{e^{Bpd/V_b}}{pA}$$ on d. $$\frac{1}{\alpha d} = \frac{e^{Bpd/V_b}}{pA}$$ 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 $$\therefore \ln\left(1+\frac{1}{\gamma}\right) = K$$ $$\therefore d = \frac{e^{Bpd/V_b}}{pA} \times K \quad \text{(A)}$$				

	→ Analytical expression for minimum sparking potential can be obtained using general expression for α/p. $\frac{\alpha}{p} = A e^{-Bp/E}$ $\therefore \alpha = pA e^{-Bp/E}$ $\alpha = pA e^{-Bpd/V_b}$ $e^{Bpd/V_b} = \frac{pA}{\alpha}$ $\therefore \frac{1}{\alpha} = \frac{e^{Bpd/V_b}}{pA}$ $d \cdot \frac{1}{\alpha d} = \frac{e^{Bpd/V_b}}{pA}$ 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 $\therefore \ln\left(1 + \frac{1}{\gamma}\right) = K$ $\therefore d = \frac{e^{Bpd/V_b}}{pA} \times K$ — (A) $\therefore (pd)_{min} = \frac{e}{A} K$ $(V_b)_{min} = \frac{BeK/A}{1} = \frac{B}{A} e K$ $V_{b\,min} = 2.718 \frac{B}{A} \ln\left(1 + \frac{1}{\gamma}\right)$			
5.	Describe with a neat diagram the working of a three stage cascaded transformer. Label the power ratings of various stages of the transformer and explain why cascading more than three stages not practically possible.	[3+5+2]	CO3	L2

P.T.O

6.	Discuss the following breakdown methods in solid dielectric: (a) Thermal breakdown (b) Intrinsic breakdown 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, σ is the d.c. conductivity of the specimen. • $W_{d.c.} = E^2\sigma$ 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.*	[5+5]	CO2	L2

- 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.
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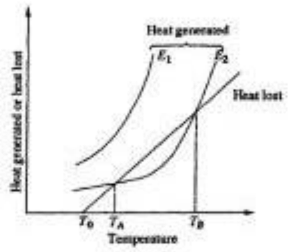

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B) **INTRINSIC BREAKDOWN**

	• 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			
7.	Write short notes on: a) Three electrode gap, b) Breakdown of eletronegative gases. • In the case of impulse current generators using three electrode gaps for tripping and control, a certain special design is needed. • The electrodes have to carry high current from the capacitor bank. • Secondly, the electrode has to switch large currents in a small duration of time (in about a microsecond). • Therefore, the switch should have very low inductance. • The erosion rate of the electrodes should be low. • For high current capacitor banks, a number of spark gap switches connected in parallel as shown in Fig. 6.25 are often used to meet the requirement. • Recently, trigatron gaps are being replaced by triggered vacuum gaps,	[5+5]	CO3, CO1	L2

Fig. 6.25 Three electrode gap for high current switching

B) Breakdown In Electronegative gases

- 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,

- In the case of impulse current generators using three electrode gaps for tripping and control, a certain special design is needed.
- The electrodes have to carry high current from the capacitor bank.
- Secondly, the electrode has to switch large currents in a small duration of time (in about a microsecond).
- Therefore, the switch should have very low inductance.
- The erosion rate of the electrodes should be low.
- For high current capacitor banks, a number of spark gap switches connected in parallel as shown in Fig. 6.25 are often used to meet the requirement.
- Recently, trigatron gaps are being replaced by triggered vacuum gaps,
- the advantage of the latter being fast switching at high currents (> 100 kA) in a few nanoseconds.
- Triggering of the spark gaps by focused laser beams is also adopted since the performance is better than the conventional triggering methods.

(b) the **dissociative attachment** in which the gas molecules split into their constituent atoms and the electronegative atom forms a negative ion.

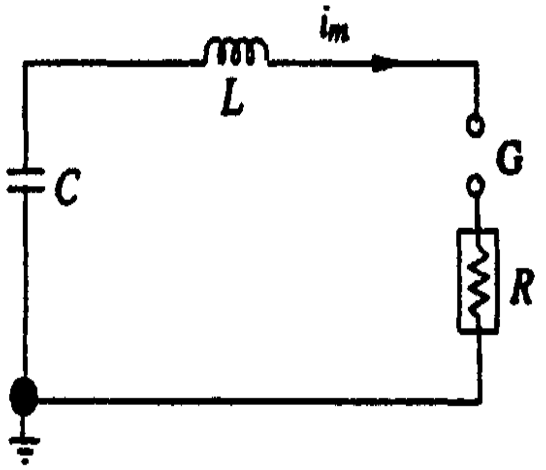
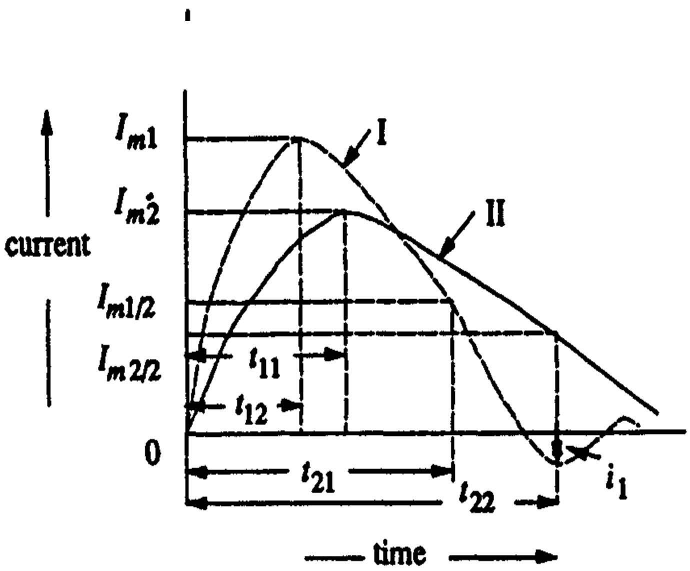
These processes may be symbolically represented as:

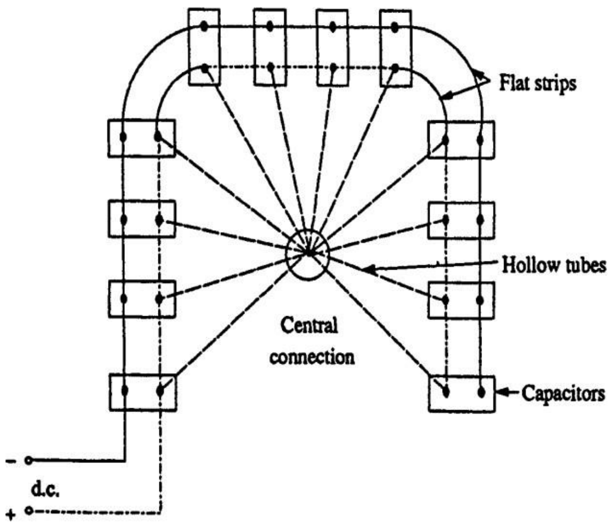
(a) Direct attachment

(b) Dissociative attachment

- A simple gas of this type is oxygen. Other gases are sulphur hexafluoride, freon, carbon dioxide, and fluorocarbons.
- In these gases, 'A" is usual y 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.**

The Townsend breakdown criterion for **attaching gases** can also be deduced by equating the denominator to zero:

8.	Write short notes on impulse current generator.  (a) Basic circuit of an impulse current generator  t_1 and t_{12} = time-to-front of waves I and II t_{21} and t_{22} = time-to-tail of waves I and II I — damped oscillatory wave II — overdamped wave i_1 — overshoot (b) Types of impulse current waveforms	[10]	CO3	L1



(c) Arrangement of capacitors for high impulse current generation

Fig. 6.20 Impulse current generator circuit and its waveform

- **For producing impulse currents of large value, a bank of capacitors connected in parallel are charged to a specified value and are discharged through a series R-L circuit as shown in Fig. 6.20.**
- **C represents a bank of capacitors connected in parallel which are charged from a d.c. source to a voltage up to 200 kV.**
- **R represents the dynamic resistance of the test object and the resistance of the circuit and the shunt.**
- **L is an air cored high current inductor, usually a spiral tube of a few turns**

If the capacitor is charged to a voltage *V and discharged when the spark gap is* triggered, the current *im will be given by the equation*

$$V = R\,i_m + L\frac{di_m}{dt} + \frac{1}{C}\int_0^t i_m\,dt$$

The circuit is usually underdamped, so that

$$\frac{R}{2} < \sqrt{L/C}$$

	$i_m = \frac{V}{\omega L} [\exp(-\alpha t)] \sin(\omega t)$ where $\alpha = \frac{R}{2L}$ and $\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ The time taken for the current i_m to rise from zero to the first peak value is $t_1 = t_f = \frac{1}{\omega} \sin^{-1} \frac{\omega}{\sqrt{LC}} = \frac{1}{\omega} \tan^{-1} \frac{\omega}{\alpha}$ The duration for one half cycle of the damped oscillatory wave t_2 is, $t_2 = \frac{\pi}{\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}}$				