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Internal Test 1 –November 2022

Sub:	High Voltage Engineering						Code:	18EE56
Date:	07/11/2022	Duration:	90 mins	Max Marks:	50	Sem:	VA & B	Branch : EEE

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

		Marks	OBE CO	RBT
1.	State and explain Paschen's law. Derive expression for (pd)min and Vbmin.	[4+6]	CO1	L2

The Townsend's Criterion

$$\gamma(e^{\alpha d} - 1) = 1$$

enables the evaluation of breakdown voltage of the gap by the use of appropriate values of α/p and γ corresponding to the values E/p *when the current is too low to damage the cathode*

- A close agreement between the calculated and experimentally determined values is obtained when the gaps are short or long and the pressure is relatively low.
- An expression for the breakdown voltage for uniform field gaps as a function of gap length and gas pressure can be derived from the threshold equation by expressing the ionization coefficient α/p *as* a function of field strength *E and gas pressure p i.e.,*

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

Substituting this, we have

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

Taking ln both the sides, we have

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

For uniform field $E = \dfrac{V_b}{d}$.

Therefore, $\quad f\left(\dfrac{V_b}{pd}\right) \cdot pd = K$

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

$$V_b = F\,(p \cdot d)$$

- This shows that the breakdown voltage of a uniform field gap is a unique function of the product of gas pressure and the gap length for a particular gas and electrode material.
- This relation is known as **Paschen's law**.
- *This relation does not mean that the breakdown voltage is directly proportional to* product pd even though it is found that for some region of the product pd the relation is linear i.e., the breakdown voltage varies linearly with the product pd.

An analytical expression for the minimum sparking potential can be obtained using the expression for α/p.

$$\frac{\alpha}{p} = Ae^{Bp/E} \qquad \text{or} \qquad \alpha = pAe^{-Bpd/V_b}$$

or

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

or

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

We know that

$$\alpha d = \ln\left(1 + \frac{1}{v}\right)$$

Therefore,

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

Assuming v to be constant, let $\ln\left(1 + \frac{1}{v}\right) = k$

Then

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

- In order to obtain minimum sparking potential, we rearrange the above expression as

$$V_b = f(pd)$$

Taking ln on both sides, we have

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

or

$$V_b = \frac{Bpd}{\ln Apd/k}$$

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

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

or

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

or

$$\ln \frac{Apd}{K} = 1$$

or

$$\ln \frac{Apd}{K} = e$$

or

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

or

$$V_{b\,min} = \frac{Be^{K/A}}{1} = \frac{B}{A} \cdot eK$$

$$V_{bmin} = 2.718 \frac{B}{A} \ln\left(1 + \frac{1}{v}\right)$$

If values of A, B and v are known both the (pd) min and V_{bmin} can be obtained. However, i

2a.	What is time-lag? Discuss its components and the factors which affect these components.	[5]	CO1	L2

- There is a time difference between the application of a voltage sufficient to cause breakdown and the occurrence of breakdown itself.
- This time difference is called the **time lag.**
- **The Townsend criterion for breakdown is satisfied, only if at least one election is present in the gap between the electrodes.**

- **In the case of applied d.c. or slowly varying (50 Hz a.c) voltages, there is no difficulty in satisfying this condition.**
- **With rapidly varying voltages of short duration (=10-6 *s), the initiatory electron may not* be present in the gap.**
- **In the absence of such an electron breakdown cannot occur.**
- **The time *t which lapses between the application of the voltage sufficient to cause* breakdown and the appearance of the initiating electron is called a statistical time lag (ts)of the gap.**
- **The appearance of electrons is usually statistically distributed.**
- **After the appearance of the electron, a time *tt is required for the ionization processes to* develop fully to cause the breakdown of the gap**
- **this time is called the formative time lag *(tt).***
- *The total time ts + tt=t is called the total time lag.*
- **Time lags are of considerable practical importance.**
- **For breakdown to occur the applied voltage V should be greater than the static breakdown voltage Vs as shown in Fig.**
- **The difference in voltage ΔV = V- Vs is called the overvoltage**
- **ratio V/Vs is called the impulse ratio.**
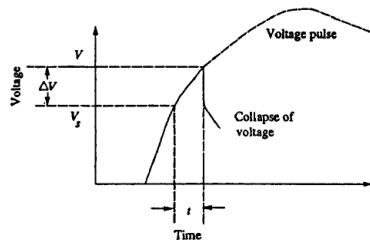
| 2b.	Discuss the breakdown phenomenon in electronegative gases.	[5]	CO1	L2
	- It has been recognized that one process that gives high breakdown strength to a gas is the electron attachment in which free electrons get attached to neutral atoms or molecules to form negative ions. - Since negative ions 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** *the direct* attachment in which an electron directly attaches to form a negative ion, **(b) the dissociative attachment in which the gas molecules split into their constituent atoms and the electronegative atom forms a negative ion.** **These processes may be symbolically represented as:** *Direct attachment* $$AB + e \longrightarrow AB^-.$$ *Dissociative attachment* $$AB + e \longrightarrow A + B^-$$ **A simple gas of this type is oxygen. Other gases are sulphur hexafluoride, freon, carbon dioxide, and fluorocarbons.**			

- In these gases, 'A" is usually sulphur or carbon atom, and 'B* is oxygen atom or one of the halogen atoms or molecules.
- With such gases, the Townsend current growth equation is modified to include ionization and attachment
- An attachment coefficient (η) is defined, as the number of attaching collisions made by one electron drifting one centimetre in the direction of the field.
- Under these conditions the current reaching the anode, can be written as:

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

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- This shows that for $\eta < \alpha$ breakdown is always possible irrespective of the values of α, η, γ
- If on the other hand, $\eta > \alpha$ *Equation approaches an asymptotic form with increasing value of d,*
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3.	Discuss the following breakdown methods in solid dielectric; (i) thermal breakdown; (ii) electro-mechanic breakdown.	[5+5]	CO2	L2

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

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

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

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

-
- where, f= frequency in Hz,
- δ= loss angle of the dielectric material, and
- E- rms value.

$$W_T = C_V \frac{dT}{dt} + div(K\ grad\ T)$$

-
- 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 the heat dissipated (WT).
- In actual practice there is always some heat that is radiated
- out).
- Breakdown occurs when Wd.c. or *Wa.c. exceeds WT.*
- *The thermal instability* condition is shown in Fig.
- Here, the heat lost is shown by a straight line
- the heat generated at fields *E1 and E2 are shown by separate curves.*
- *At field EI* breakdown occurs both at temperatures *TA and TB*
- In the temperature region of TA and TB heat generated is less than the heat lost for the field E2 **the breakdown will not occur.**
- This is of great importance to practising engineers, as most of the insulation failures in high voltage power apparatus occur due to thermal breakdown.
- Thermal breakdown sets up an upper limit for increasing the breakdown voltage when the thickness of the insulation is increased.
- For a given loss angle and applied stress, the heat generated is proportional to the frequency and hence thermal breakdown is more serious at high frequencies.

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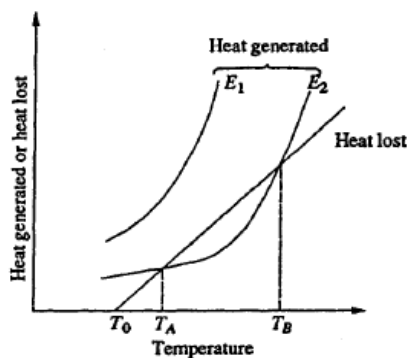
ELECTROMECHANICAL   BREAKDOWN
- When solid dielectrics are subjected to high electric fields, failure occurs due to electrostatic compressive forces which can exceed the mechanical compressive strength.
- If the thickness of the specimen is *d0 and is compressed to* a thickness *d under an applied voltage 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.*

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

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

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4.	Write short notes on different secondary ionizing process with respect to gaseous medium.	[10]	CO1	L2

- **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
- **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.

- **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.

$$h.v \geq \varphi \qquad v = \frac{\varphi}{h}$$

- The frequency (v) is given by the relationship is threshold frequency.
- 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 φ is typically a few electron volts, the threshold frequency lies in the far ultra-violet region of the electromagnetic radiation spectrum.
- Instantaneous recombination between positive ions and electrons releases photons which in turn generate secondary electrons by the photoionization process
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- **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 ($10 \sim 8s$).
- 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. • •			
5.	Explain the following methods of breakdown of liquid dielectrics, (i) cavity breakdown (Bubbles Theory); (ii) suspended particle theory. **Cavitation and the Bubble Theory** • experimentally observed that in many liquids, the breakdown strength depends strongly on the applied **hydrostatic pressure.** • suggesting that a change of phase of the medium is involved in the breakdown process, which means kind of **vapour bubble** formed is responsible for breakdown. The following processes are responsible for **formation of the vapour bubbles**: • *(a)* **Gas pockets at the surfaces of the electrodes;** • *(b)* **electrostatic repulsive forces between space charges which may be sufficient to overcome the surface tension**; • (c) **gaseous products due to the dissociation of liquid molecules by electron collisions** • *(d)* **vaporizations of the liquid by corona type discharge from sharp points and irregularities on the electrode surfaces**. • Once a bubble is formed it will elongate in the direction of the electric field under the influence of electrostatic forces. • The volume of the bubble remains constant during elongation. • Breakdown occurs when the voltage drop along the length of the bubble becomes equal to the minimum value on the Paschen's curve The breakdown field is given as $$E_0 = \frac{1}{(\varepsilon_1 - \varepsilon_2)}\left[\frac{2\pi\sigma(2\varepsilon_1 + \varepsilon_2)}{r}\left\{\frac{\pi}{4}\sqrt{\left(\frac{V_b}{2rE_0}\right)} - 1\right\}\right]^{\frac{1}{2}}$$ • Where б is the surface tension of the liquid, • ε 1 is the permittivity of the liquid, • ε2 is the permittivity of the gas bubble, • r is the initial radius of the bubble assumed as a sphere • Vb is the voltage drop in the bubble (corresponding to minimum on the Paschen's curve). • From this equation, it can be seen that the breakdown strength depends on the initial size of the bubble which in turn is influenced by the hydrostatic pressure and temperature of the liquid. This theory does not take into account the production of the initial bubble and hence the results given by this theory do not agree well with the experimental results	[5+5]	CO1	L2
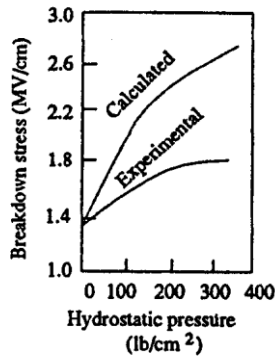
Suspended Particle Theory
- In commercial liquids, the presence of solid impurities cannot be avoided.
- These impurities will be present as fibrous or as dispersed solid particles.
- The permittivity of these particles (ε_1) will be different from the permittivity of the liquid (ε_2).
- If we consider these impurities to be spherical particles of radius r, and if the applied field is E, then the particles experience a force F, where

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

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

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

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

- 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 $dE/dx \to 0$ 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)
- $F_v = 6\pi\eta r v$
- 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

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

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

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

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

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

$$v = vd$$

We have

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

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

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

6.	The following table gives two sets of experimental results for studying Townsend's mechanism. The field is kept constant in each set: The minimum current observed is 6×10^{-14} A. Determine the values of Townsend's first and second ionization coefficients.	[10]	CO1	L3

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

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

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

will give us the value of α.

Let us take gap distances of 2 and 2.5 mm.

The respective $\ln I/I_0$ are

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

and

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

$\therefore$ The slope $= \dfrac{4.5362 - 3.2188}{0.05} = 26.34$

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

We know that

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

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

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

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

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

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

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

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

$$\frac{I}{I_0} = 2\times10^5 = \frac{e^{8.1\times0.5}}{1-\gamma(e^{4.05}-1)}$$

$$2\times10^5 = \frac{57.39}{1-\gamma(56.39)}$$

or $$\frac{200\times10^3}{57.39} = 3.4849\times10^3 = \frac{1}{1-56.39\gamma}$$

$$2.87\times10^{-4} = 1 - 56.39\,\gamma$$

$$56.39\gamma = 1.0$$

or

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

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