Question 1

(a) Gas ionization processes

- a. Ionization by simple collision
- b. Excitation
- c. Ionization by Double electron impact
- d. Photo-ionization
- e. Electron Attachment
- f. Electron detachment
- g. Other Processes
    - i. ion-atom collisions
    - ii. excited atom-molecule collisions
    - iii. atom-atom collisions

Ionisation by simple collision Process

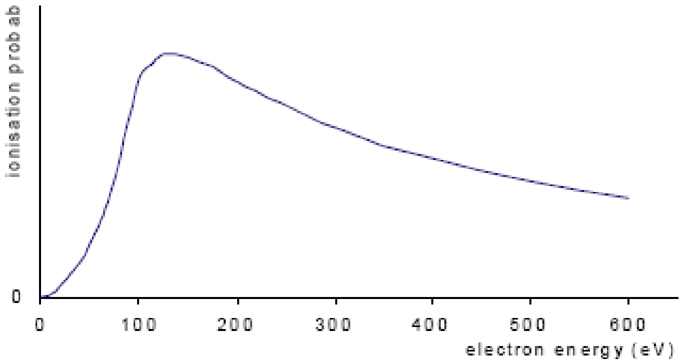
When the kinetic energy of an electron (½ mu^2), in collision with a neutral gas molecule exceeds the ionisation energy ($E_i = e V_i$) of the molecule, then ionisation can occur.
(i.e. when $\frac{1}{2} mu^2 > E_i$)

$$M + e^- (\tfrac{1}{2} mu^2) \rightarrow M^+ + 2e^-$$

In general, a positive ion and 2 slow moving electrons will result. The probability of this process is zero for electron energies equal to the ionisation energy Ei, but increases almost linearly at first, and then gradually with electron energy up to a maximum.

When the gas molecules are bombarded with electrons, other electrons bound to atoms may be freed by the collision with the high energy electron. The ratio of the electrons given by collision to the primary electrons depend, mainly on the energy of the primaries. This is maximum at primary electron energies of about 200 - 500 eV. For lower energy values, the energy transferred may not be sufficient to cause electrons to escape from the surface of the molecules, and thus the probability of ionisation is small. For much higher values of primary energies, the energy of the impinging electron would be sufficient for this electron to penetrate the surface deeper into the molecule, so that again the chance of escape of other electrons decreases.

Thus the variation of the ionisation probability in air with increase of electron energy is as shown in figure below,

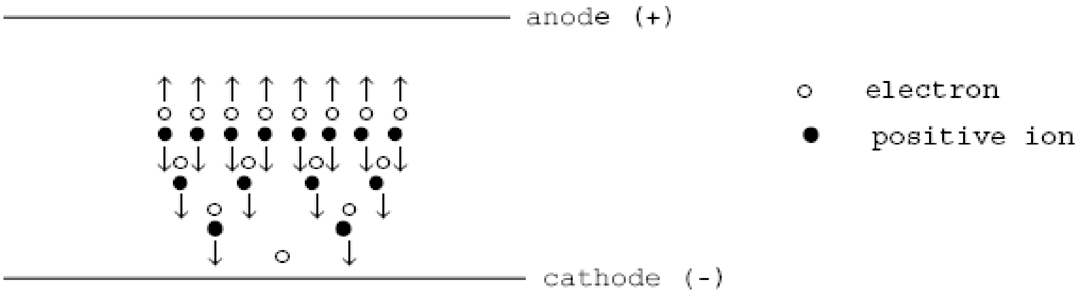


(b) Avalanche Mechanism in breakdown process of gaseous dielectrics

This process is based on the generation of successive secondary avalanches to produce breakdown.

Suppose a free electron exists (caused by some external effect such as radio-activity or cosmic radiation) in a gas where an electric field exists. If the field strength is sufficiently high, then it is likely to ionize a gas molecule by simple collision resulting in 2 free electrons and a positive ion. These 2 electrons will be able to cause further ionization by collision leading in general to 4 electrons and 3 positive ions. The process is cumulative, and the number of free electrons will go on increasing as they continue to move under the action of the electric field. The swarm of electrons and positive ions produced in this way is called an electron avalanche. In the space of a few millimeters, it may grow until it contains many millions of electrons.

The process is shown in figure below,



(c) Determination expressions for Townsend's first and second ionization coefficients

When the voltage applied across a pair of electrodes is increased, the current throughout the gap increases slowly, as the electrons emitted from the cathode move through the gas with an average velocity determined by their mobility for the field strength existing for the particular value of voltage. Impact ionization by electrons is probably the most important process in the breakdown of gasses, but this process alone is not sufficient to produce breakdown.

Let n0 = number of electrons/second emitted from the cathode,

nx = number of electrons/second moving at a distance x from the cathode [nx > n0 due to ionising collisions in gap]

α = number of ionising collisions, on average, made by one electron per unit drift in the direction of the field. [Townsend's first ionisation coefficient]

Then 1/α = average distance traversed in the field direction between ionising collisions.

Consider a laminar of thickness dx at a distance x from the cathode. The nx electrons entering the laminar will traverse it in the presence of the applied field E. The ionising collisions generated in the gas gap will be proportional to both dx and to nx.

Thus

dnx □∝nx

□ . ∝dx

Therefore dnx = α. nx . dx (from definition of _)

Rearranging and integrating gives

$$\int_{n_0}^{n_x} \frac{d\,n_x}{n_x} = \alpha \int_0^x dx$$

$$\log_e (n_x / n_0) = \alpha . x$$

$$n_x = n_0 \cdot e^{\alpha x}$$

If the anode is at a distance x = d from the cathode, then the number of electrons nd striking the anode per second is given by

$$n_d = n_0 . e^{\alpha d}$$

Therefore, on the average, each electron leaving the cathode produces (nd - n0)/n0 new electrons (and corresponding positive ions) in the gap.

In the **steady state**, the number of positive ions arriving at the cathode/second must be exactly equal to the number of newly formed electrons arriving at the anode. Thus the circuit current will be given by

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

where I0 is the initial photo-electric current at the cathode.

In the actual breakdown process, the electron impact ionization is attended by secondary processes on the cathode, which replenish the gas gap with free electrons, with every newly formed avalanche surpassing the preceding one in the number of electrons.

Consider now the current growth equations with the secondary mechanism also present.

Let γ = number of secondary electrons (on average) produced at the cathode per ionising collision in the gap. [Townsend's second ionisation coefficient]
n0 = number of primary photo-electrons/second emitted from the cathode
n0' = number of secondary electrons/second produced at the cathode
n0" = total number of electrons/second leaving the cathode

Then n0' = n0 + n0"

On the average, each electron leaving the cathode produces [$e^{\alpha d}$ - 1] collisions in the gap, giving the number of ionizing collisions/second in the gap as n0" ($e^{\alpha d}$ - 1). Thus by definition

$$\gamma = \frac{n_{0'}}{n_0''(e^{\alpha d} - 1)}$$

giving $n_{0'} = \gamma\, n_0''(e^{\alpha d} - 1)$
but $n_0'' = n_0 + n_{0'}$
so that $n_0'' = n_0 + n_0''(e^{\alpha d} - 1) . \gamma$

This gives the result

$$n_0'' = \frac{n_0}{1 - \gamma\,(e^{\alpha d} - 1)}$$

Similar to the case of the primary process (with α only), we have

$$n_d = n_0'' e^{\alpha d} = \frac{n_0 e^{\alpha d}}{1 - \gamma (e^{\alpha d} - 1)}$$

Thus, in steady state, the circuit current I will be given by

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

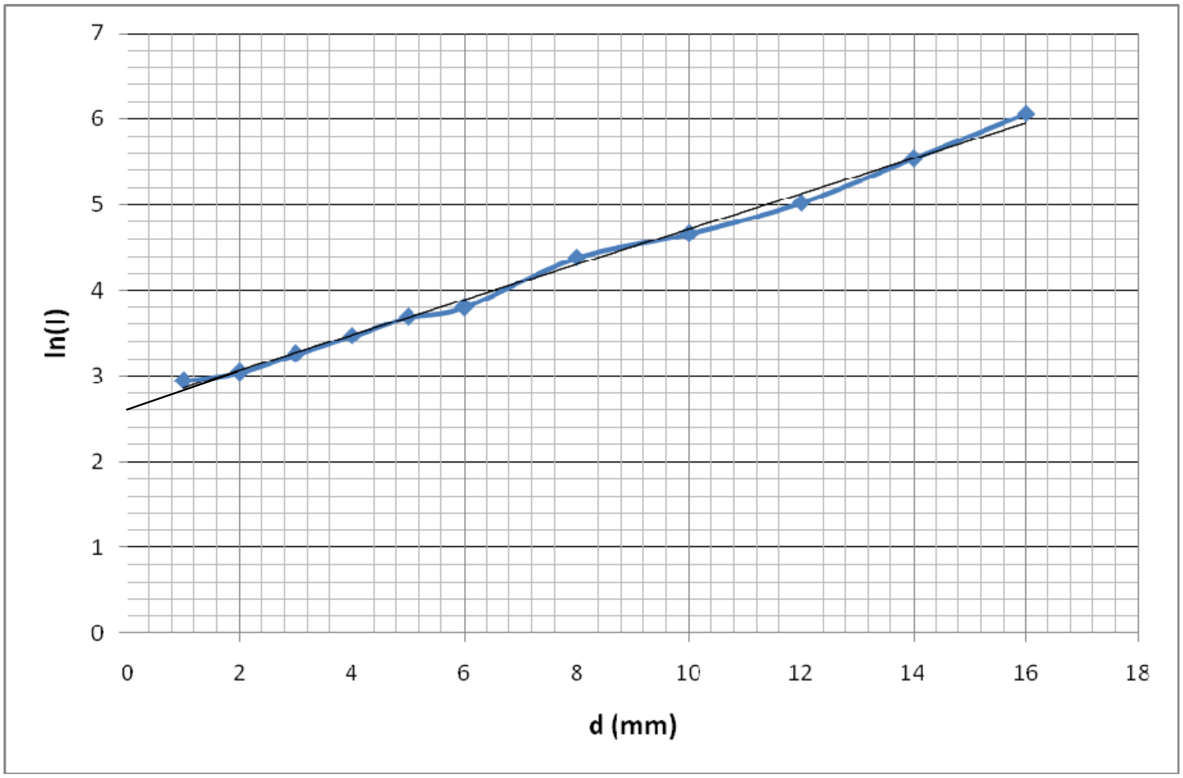
Determination expressions for Townsend's first and second ionization coefficients

From the Townsend mechanism, the discharge current is given by

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

When $\alpha d >> 1$

$$\ln I = \alpha d + \ln I_0$$



From the graph,

Gradient, α = (5.57-3)/(14-1.6)

= 0.207 mm^{-1}

Intercept = $\ln(I_0)$ = 2.65 = 14.15 pA

Substituting for high value d,

$$460 = \frac{14.15\, e(0.207x16)}{1-\gamma(e(0.207x16)-1)}$$

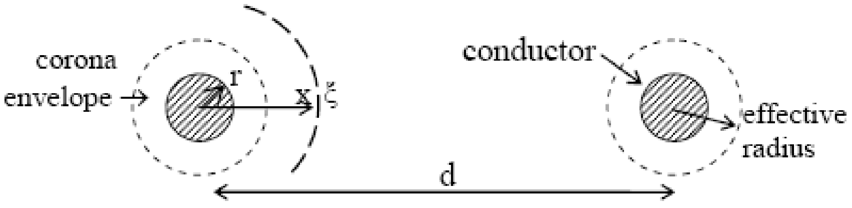
$\gamma = 5.897 \times 10^{-3}$

Question 2

(a) Expression for corona inception

When a voltage is applied, the stress surrounding a conductor is a maximum at the conductor surface itself, and decreases rapidly as the distance from the conductor increases. Thus when the stress has been raised to critical value immediately surrounding the conductor, ionisation would commence only in this region and the air in this region would become conducting. The effect is to increase the effective conductor diameter while the voltage remains constant. This results in two effects. Firstly, an increase in the effective sharpness of the conductor would reduce the stress outside this region, and secondly, this would cause a reduction of the effective spacing between the conductors leading to an increase in stress. Depending on which effect is stronger, the stress at increasing distance can either increase or decrease. If the stress is made to increase, further ionisation would occur and flashover is inevitable.

The condition for stable corona can be analyzed as follows.



The electric stress ξ at a distance x from a conductor of radius r, and separated from the return conductor by a distance d is given by,

$$\xi = \frac{1}{\varepsilon_0} \cdot \frac{q}{2\pi x l}$$

where q is the charge on each conductor in length *l*.
Thus the potential V can be determined from

$$V = \int \xi dx = \int_r^{d-r} \frac{q}{2\pi x \varepsilon_0} . dx$$

Since both charges (+q and -q) produce equal potential differences, the total potential difference between the two conductors is double this value. Thus the conductor to neutral voltage, which is half the difference would be equal to this value is given by

$$V = \frac{q}{2\pi \varepsilon_0} . \log_e \left(\frac{d-r}{r} \right)$$

Therefore the electric stress at distance x is given by,

$$\xi_x = \frac{V}{x \log_e \frac{d-r}{r}}, \quad \xi_x = \frac{V}{x \log_e \frac{d}{r}} \quad \text{if } d \ll r$$

Under ordinary conditions, the breakdown strength of air, and hence the inception of corona ξmax can be taken as 30 kV/cm (peak value) or ξrms = 30/√2 = 21.2 kV/cm.

Since there is no electric stress within the conductor, the maximum stress will occur when x is a minimum, that is at x = r.

Thus if E0,rms is the rms value of the disruptive critical voltage to neutral,

$$\xi_{rms} = 21.2 = \frac{E_{0,rms}}{r \log_e \frac{d}{r}}$$

When the surface of the conductor is irregular, it is more liable to corona. Thus an irregularity factor m0 is introduced to account for this reduction. Typical values of this factor range from 0.98 for a roughened conductor down to about 0.85 for a 7 strand cable.

Corona will of course be affected by the physical state of the atmosphere, and hence by the air density. An air density correction factor δ is introduced, given by the usual expression, with **p** being the pressure expressed in **torr** and **t** being the temperature expressed in ^{0}C.

$$\delta = \frac{p}{760} \cdot \frac{273+20}{273+t} = \frac{0.386\, p}{273+t}$$

The disruptive critical voltage can then be written as in the following equation.

$$E_{0,rms} = 21.2\, \delta\, m_0\, r \log_e (d/r) \qquad \text{kV to neutral}$$

(b) Stable corona formation

Consider two conductors, just on the limit of corona formation. Assume that there is a thin layer Δr of ionised air around each conductor, so that the effective radius becomes (r + Δr). The change in electric stress Δε due to this layer can be determined using differentiation.

Thus

$$\Delta\xi = \Delta\left(\frac{E}{r\log_e\frac{d}{r}}\right)$$

$$\Delta\xi = \left[\frac{-E}{(r\log_e\frac{d}{r})^2}.\left(\log_e\frac{d}{r} + r.\frac{r}{d}.\frac{-d}{r^2}\right)\right].\Delta r$$

$$\Delta\xi = \frac{E(1-\log_e\frac{d}{r}).\Delta r}{(r\log_e\frac{d}{r})^2}$$

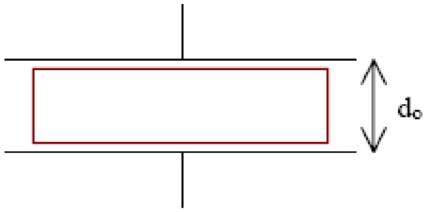
When loge > 1, the above expression is negative. i.e. d/r > e (=2.718)

Under this condition, the effective increase in diameter lowers the electric stress and no further stress increase is formed, and corona is stable. If on the other hand, d/r < e, then the effective increase in the diameter raises the electric stress, and this causes a further ionisation and a further increase in radius, and finally leads to flash-over.

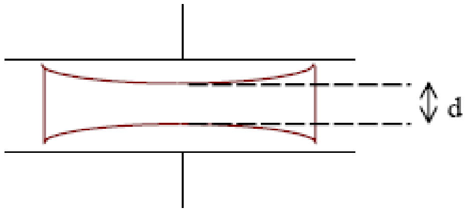
(c) Breakdown processors of soild insulation

a. Electro-mechanical breakdown

When an electric field is applied to a dielectric between two electrodes, a mechanical force will be exerted on the dielectric due to the force of attraction between the surface charges. This compression decreases the dielectric thickness thus increasing the effective stress. This is shown in figure below,



In the absence of field



With applied field

Compressive force

$$P_c = ½\, D\, E = ½\, \varepsilon_o\, \varepsilon_r\, V^2/d^2,$$

and From Hooke's Law for large strains,

$$P_c = Y \ln (d_o/d)$$

At equilibrium, equating forces gives the equation,

$$V^2 = \frac{2Y}{\varepsilon_o \varepsilon_r} d^2 \ln\frac{d_o}{d}$$

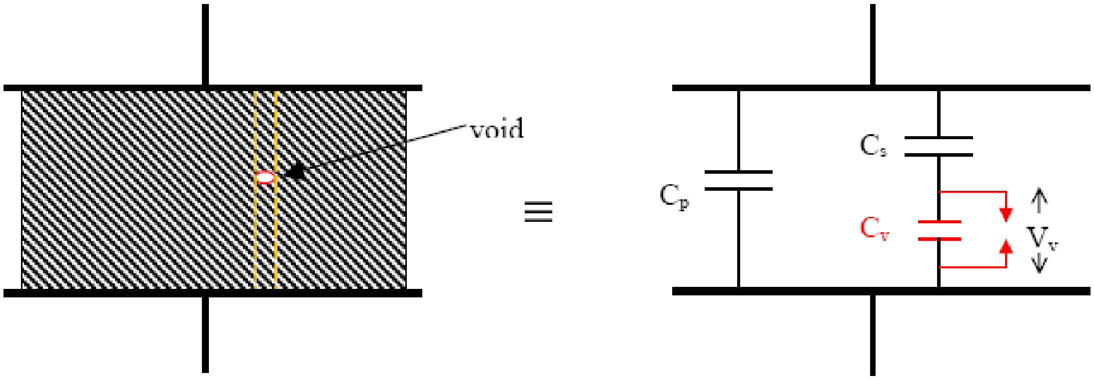
By differentiating with respect to d, it is seen that the system becomes unstable when ln (do/d) > ½ or d < 0.6
do.

Thus when the field is increased, the thickness of the material decreases. At the field when d < 0.6 do, any further increase in the field would cause the mechanical collapse of the dielectric. The apparent stress (V/do) at which this collapse occurs is thus given by the equation

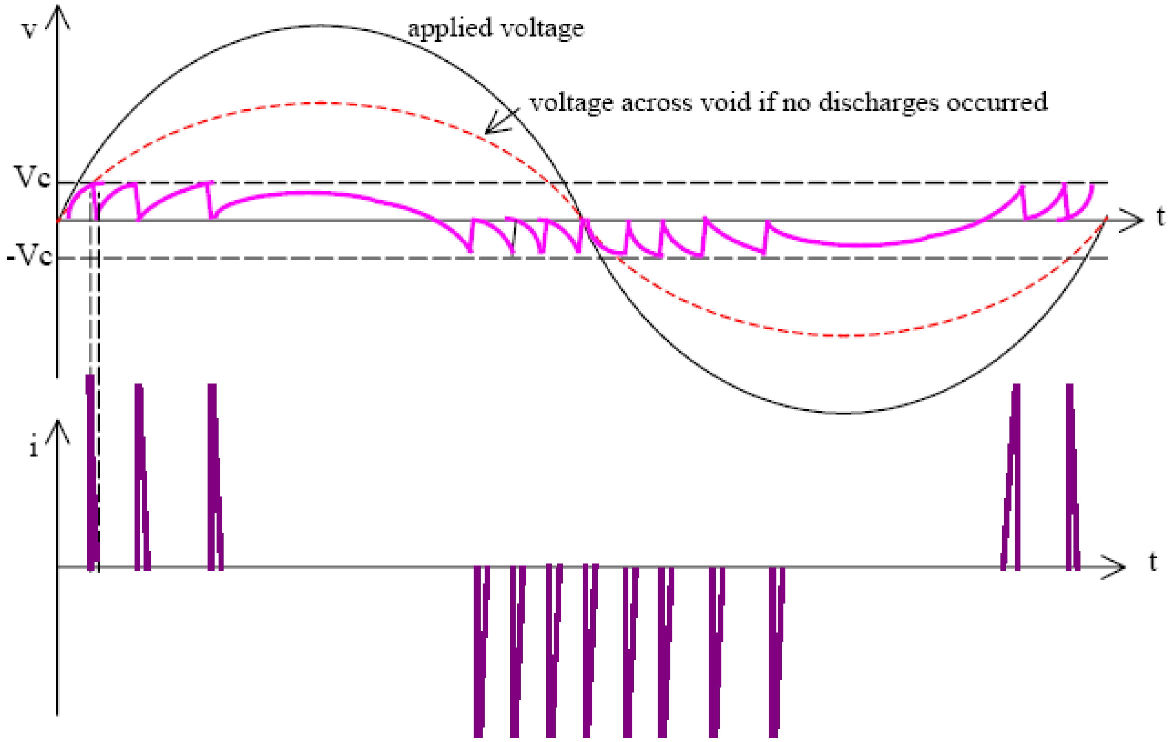
$$E_a = 0.6\left[\frac{Y}{\varepsilon_o \varepsilon_r}\right]^{\frac{1}{2}}$$

b. **Breakdown due to internal discharges**

Solid insulating materials sometimes contain voids or cavities in the medium or boundaries between the dielectric and the electrodes. These voids have a dielectric constant of unity and a lower dielectric strength. Hence the electric field strength in the voids is higher than that across the dielectric. Thus even under normal working voltages, the field in the voids may exceed their breakdown value and breakdown may occur. The mechanism can be explained by considering the following equivalent circuit of the dielectric with the void, shown in figure below,



When the voltage Vv across the void exceeds the critical voltage Vc, a discharge is initiated and the voltage collapses. The discharge extinguishes very rapidly (say 0.1 _s). The voltage across the void again builds up and the discharges recur. The number and frequency of the discharges will depend on the applied voltage. The voltage and current waveforms (exaggerated for clarity) are shown in figure below,



In each of the discharges, there will be heat dissipated in the voids which will cause carbonization of the surface of the voids and erosion of the material. The gradual erosion of the material and consequent reduction in the thickness of the insulating material eventually leads to breakdown. Breakdown by this process is slow and may occur in a few days or may take a few years.

c. **Surface Breakdown**

Surface flashover

Surface flashover is a breakdown of the medium in which the solid is immersed. The role of the solid dielectric is only to distort the field so that the electric strength of the gas is exceeded.

The three essential components of the surface flashover phenomena are

- the presence of a conducting film across the surface of the insulation
- a mechanism whereby the leakage current through the conducting film is interrupted with the production of
  sparks,
- degradation of the insulation must be caused by the sparks.

The conducting film is usually moisture from the atmosphere absorbed by some form of contamination. Moisture is not essential as a conducting path can also arise from metal dust due to wear and tear of moving parts. Sparks are drawn between moisture films, separated by drying of the surface due to heating effect of leakage current, which act as extensions to the electrodes. {For a discharge to occur, there must be a voltage at least equal to the Paschen minimum for the particular state of the gas. For example, Paschen minimum in air at N.T.P it is 380 V, whereas tracking can occur at well below 100 V. It does not depend on gaseous breakdown.] Degradation of the insulation is almost exclusively the result of heat from the sparks, and this heat either carbonises if tracking is to occur, or volatilises if erosion is to occur. Carbonization results in a permanent extension of the electrodes and usually takes the form of a dendritic growth. Increase of creepage path during design will prevent tracking, but in most practical cases, moisture films can eliminate the designed creepage path.

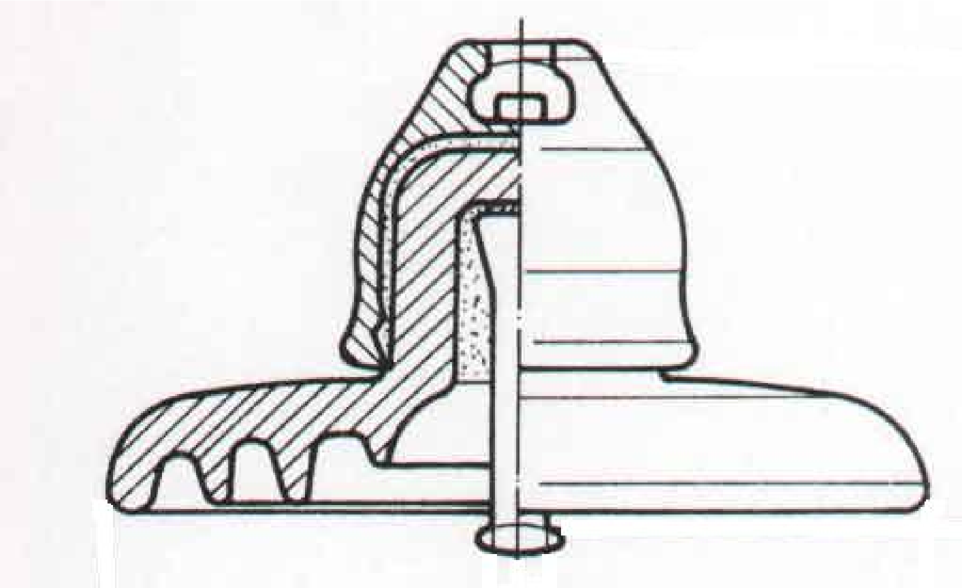
d. **Electro-chemical Breakdown**

No insulant is completely free of ions, a leakage current will flow when an electric field is applied. The ions may arise from dissociation of impurities or from slight ionisations of the insulating material itself. When these ions reach the electrodes, reactions occur in accordance with Faraday's law of electrolysis, but on a much smaller scale. The insulation and the electrode metal may be attacked, gas may be evolved or substance may be deposited on the electrodes. The products of the electrode reaction may be chemically or electrically harmful and in some cases can lead to rapid failure of the insulation.

(d) Creepage distance associated with HV insulators

Creepage is the shortest path between two conductive parts (or between a conductive part and the bounding surface of the equipment) measured along the surface of the insulation. A proper and adequate creepage distance protects against tracking, a process that produces a partially conducting path of localized deterioration on the surface of an insulating material as a result of the electric discharges on or close to an insulation surface.

The creepage distance of a disc insulator can be increase by creating grooves on the insulator as shown in the figure below,

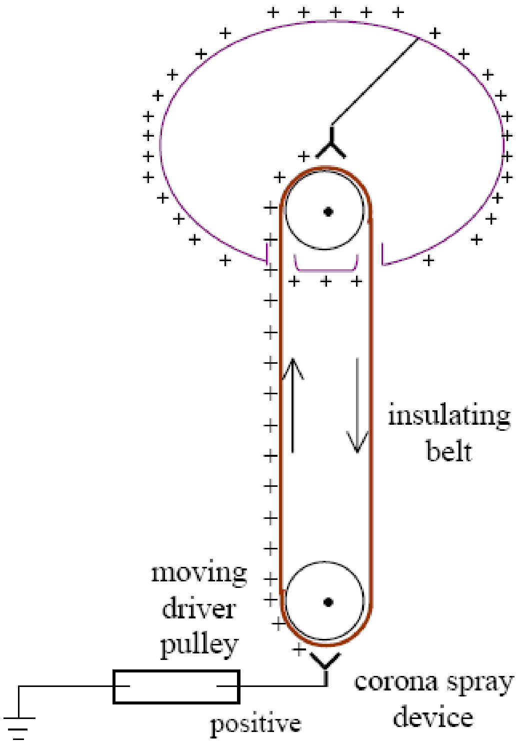


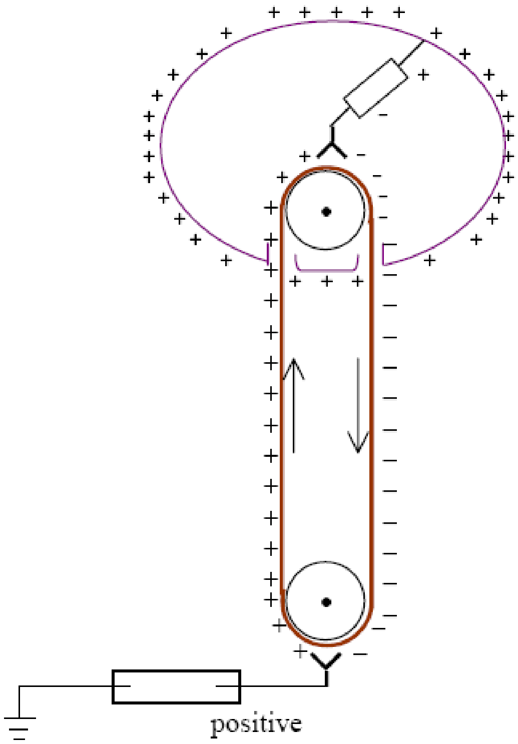
Question 3

(a) One form of electrostatic generators used in generating high dc voltages

Van de Graeff generator

The Van de Graeff generator is one of the methods used to obtain very high voltages. However they cannot supply much currents and the power output is restricted to a few kilowatt, and their use is restricted to low current applications.





The Van de Graeff generator uses an insulating belt as the carrier of charge. The generator consists of a low direct voltage source, with corona discharge taking place at the positive end of the source. The corona formation (spray) is caused by a core like structure with sharp points (corona spray device). Charge is sprayed onto the belt at the bottom by corona discharges at a potential of 10 to 100 kV above earth and carried to the top of the column and deposited at a collector. The upper electrode at which the charge is collected has a high radius of curvature and the edges should be curved so as to have no loss. The generator is usually enclosed in an earthed metallic cylindrical vessel and is operated under pressure or in vacuum.

The higher voltage of the upper electrode arises from the fact that for the same charge, a smaller capacitance gives a larger voltage. The upper electrode has a smaller capacitance to earth on account of the larger spacing involved.

$$V = \frac{Q}{C}$$

The potential of the high voltage electrode rises at a rate of

$$\frac{dV}{dt} = \frac{1}{C}\frac{dQ}{dt} = \frac{I}{C}$$

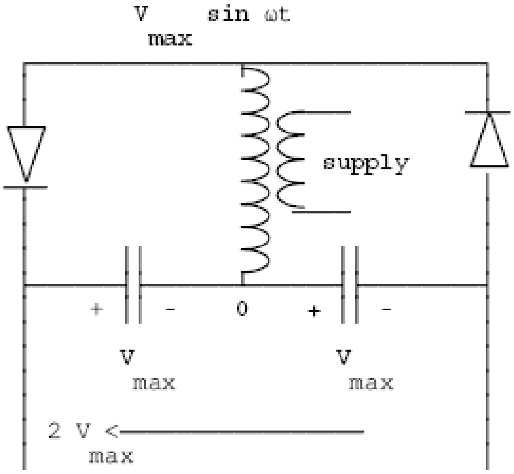
where I is the net charging current

A steady potential will be reached by the high voltage electrode when the leakage currents and the load current are equal to the charging current. The edges of the upper electrode are so rounded as to avoid corona and other local discharges.

With a single source at the lower end, the belt moves upwards with a positive charge and returns uncharged. Charging can be made more effective by having an additional charge of opposite polarity sprayed onto the belt by a self inducing arrangement (negative corona spray). using an ingenious method. this arrangement effectively doubles the charging rate.

(b) Voltage doubler circuit

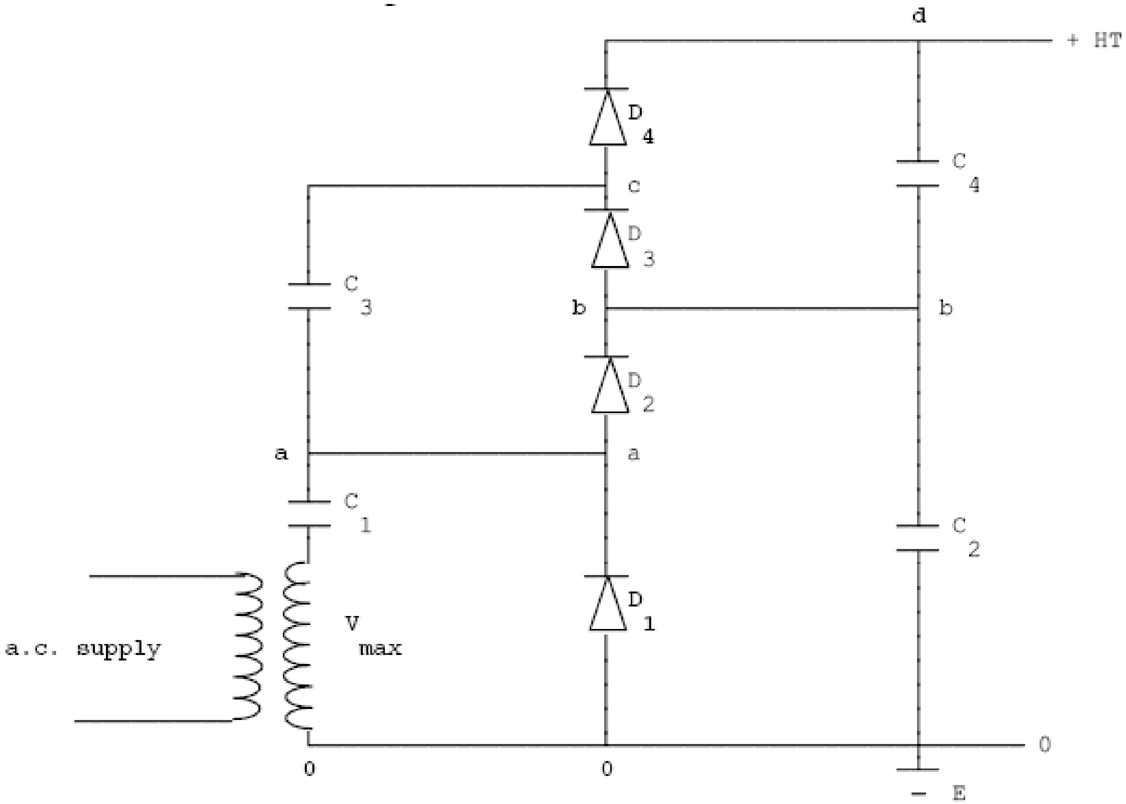
The voltage doubler circuit makes use of the positive and the negative half cycles to charge two different capacitors. These are then connected in series aiding to obtain double the direct voltage output.



In this case, the transformer will be of small rating that for the same direct voltage rating with only simple rectification. Further for the same direct voltage output the peak inverse voltage of the diodes will be halved.

(c) Cockroft Walton dc generator

When more than doubling of the voltage is required, the Cockroft-Walton voltage multiplier circuit is commonly used.



Let **Vmax** be the peak value of the secondary voltage of the high voltage transformer. To analyze the behaviour, let us consider that charging of capacitors actually takes place stage by stage rather than somewhat simultaneously. This assumption will not invalidate the result but will make analysis easier to follow. Consider the first part of the circuit containing the diode **D1**, the capacitor **C1**, and the secondary winding. During the first negative half cycle of the applied voltage, the capacitor **C1** charge up to voltage **Vmax**. Since during the positive half cycle which follows, the diode **D1** is reverse biassed, the capacitor **C1** will not discharge (or will not charge up in the other direction) and the peak of this half cycle, the point **a** will be at **2 Vmax**. During the following cycles, the potential at **a** will vary between **0** and **2 Vmax**, depending on whether the secondary voltage and the capacitor voltage are opposing or assisting.

Initially, capacitor C2 would be uncharged, and the voltage at **b** would be zero. Thus as the voltage at **a** varies between 0 and 2 Vmax, the diode D2 is forward biassed, and the capacitor C2 would charge to 2 Vmax. Once the voltage at **b** has reached 2 Vmax, the voltage at **a** would be less than or equal to the voltage at **b**. Thus once C2 has charged up, this diode too would be reverse biassed and the capacitor C2 would not discharge. The voltage at **b** would now remain constant at 2 Vmax. C3 is also initially assumed uncharged. Since the voltage at **a** varies between 0 and 2 Vmax, the diode D3 would initially be forward biassed for almost the whole cycle. Thus the capacitor C3 charges until it reaches 2 Vmax when **b** is 2 Vmax and **a** is 0. As the voltage at **a** again increases to 2 Vmax, the voltage at **c** increases, and thus the diode D3 is reverse biassed and C3 would not discharge. Now as **a** reaches 2 Vmax the voltage at **c** rises to 4 Vmax, as C3 has not discharged.

Thus after charging up has taken place, the voltage at **c** varies between 2 Vmax and 4 Vmax. Assuming C4 also to be initially uncharged, since the voltage at **b** is a constant at 2 Vmax and the voltage at **c** varies between 2 Vmax and 4 Vmax initially, during most of the cycle, the diode D4 is forward biassed and C4 charges up to the maximum difference between **d** and **b** (i.e. to 2 Vmax). This occurs when the voltage at **c** is 4 Vmax and the voltage at **d** would now be 4 Vmax. As the voltage at **c** falls from 4 Vmax to 2 Vmax, since the capacitor C4 has charged up it would not discharge, since there is no discharge path. Thus once the capacitors are charged up the voltage at **d** remains constant at 4 Vmax.

When the generator is used for a test, or when it is loaded, a current is drawn from the generator, and the capacitors lose some of their charge to the load, and the voltage falls slightly depending on the load. As the voltage across any of the capacitors drops, then at some point in the applied alternating voltage cycle, the corresponding diode would become forward biassed and charging up of the capacitor would once again result. Thus when a load is connected, there would be a small ripple in the output voltage.

(d) Use of direct voltages to test the insulation strength of AC cables

The use of alternating voltage to test insulation strength of AC cables become impractical due to the steady high charging currents. Therefore high capacity transformers required for extra high tension alternating voltage tests. Further due to transport difficulties, alternating voltage tests cannot be performed after installation.

The d.c test is not complete equivalent to the corresponding a.c. conditions, it is the leakage resistance which would determine the voltage distribution, while in the a.c. conditions, it is the layers of different dielectrics that determine the voltage distribution in the cable. Although the electric field differs in the 2 cases, it is likely that the cable will stand up to the required a.c. voltage.

Question 4

(a) Deflecting torque of an electrostatic voltmeter

When two parallel conducting plates (cross section area **A** and spacing **x**) are charged **q** and have a potential difference **V**, then the energy stored in the is given by

$$\text{Energy stored } W = \tfrac{1}{2} C V^2 \text{ so that change } dW = \tfrac{1}{2} V^2 dC = F\,dx$$

$$\therefore \text{ Force } F = \tfrac{1}{2} V^2 \frac{dC}{dx} \text{ N}$$

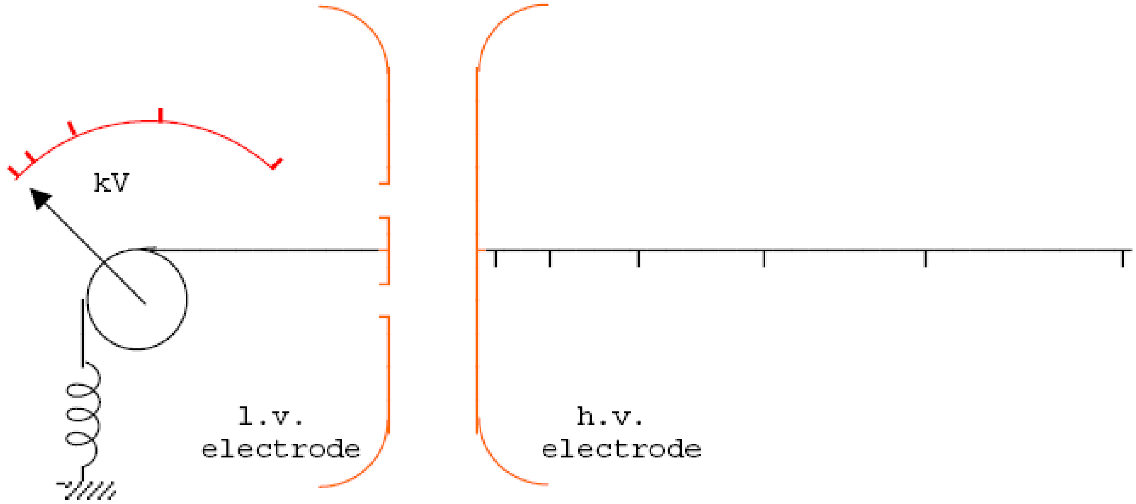
$$\text{for uniform field Capacitance } C = \frac{A\varepsilon}{x} \text{ so that } \frac{dC}{dx} = -\frac{A\varepsilon}{x^2}$$

$$\therefore F = -\tfrac{1}{2} A\varepsilon \frac{V^2}{x^2} \text{ N}$$

It is thus seen that the force of attraction is proportional to the square of the potential difference applied, so that the meter reads the square value (or can be marked to read the rms value).

(b) Abraham voltmeter

The Abraham voltmeter is the most commonly used electrostatic meter in high voltage testing equipment. In this instrument, there are two mushroom shaped hollow metal discs.



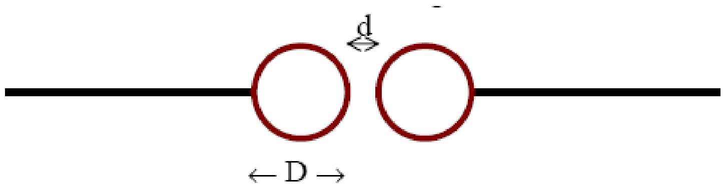
As shown in figure the right hand electrode forms the high voltage plate, while the centre portion of the left hand disc is cut away and encloses a small disc which is movable and is geared to the pointer of the instrument. The range of the instrument can be altered by setting the right hand disc at pre-marked distances. The two large discs form adequate protection for the working parts of the instrument against external electrostatic disturbances. These instruments are made to cover ranges from 3 kV to 500 kV. Owing to the difficulty of designing electrostatic voltmeters for the measurement of extra high voltages which will be free from errors due to corona effects, within the instrument, and to the external electrostatic fields, a number of special methods have been devised for the purpose.

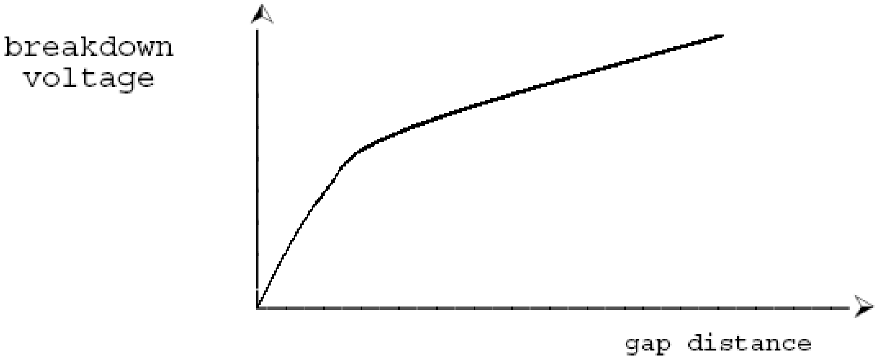
(c) Sphere gap method to measure high voltage

The sphere gap method of measuring high voltage is the most reliable and is used as the standard for calibration purposes.
The breakdown strength of a gas depends on the ionisation of the gas molecules, and on the density of the gas. As such, the breakdown voltage varies with the gap spacing; and for a uniform field gap, a high consistency, could be obtained, so that the sphere gap is very useful as a measuring device.

By precise experiments, the breakdown voltage variation with gap spacing, for different diameters and distances, have been calculated and represented in charts.

In the measuring device, two metal spheres are used, separated by a gas-gap. The potential difference between the spheres is raised until a spark passes between them. The breakdown strength of a gas depends on the size of the spheres, their distance apart and a number of other factors. A spark gap may be used for the determination of the peak value of a voltage wave, and for the checking and calibrating of voltmeters and other voltage measuring devices.





When the gap distance is increased, the uniform field between the spheres becomes distorted, and accuracy falls. The limits of accuracy are dependent on the ratio of the spacing **d** to the sphere diameter **D**, as follows.

$d < 0.5\,D$, accuracy $= \pm 3\,\%$

$0.75\,D > d > 0.5\,D$, accuracy $= \pm 5\,\%$

For accurate measurement purposes, gap distances in excess of 0.75D are not used.

The density of the gas (generally air) affects the spark-over voltage for a given gap setting. Thus the correction for any air density change must be made. The air density correction factor

$$\delta = \frac{P}{760} x \frac{273+20}{273+t} = 0.386\left[\frac{P}{273+t}\right]$$

The spark over voltage for a given gap setting under the standard conditions (760 torr pressure and at 20^0C) must be multiplied by the correction factor to obtain the actual spark-over voltage.

(d)

Breakdown voltage of a sphere gap at standard atmospheric condition = 120 kV

Applied voltage to the sphere gap at 35^0c and 765 torr, = 120 x δ

Where,

$$\delta = \frac{P}{760} x \frac{273+20}{273+t} = 0.386 \left[\frac{P}{273+t} \right]$$

$$\delta = 0.386 \left[\frac{765}{273+35} \right]$$

δ = 0.958

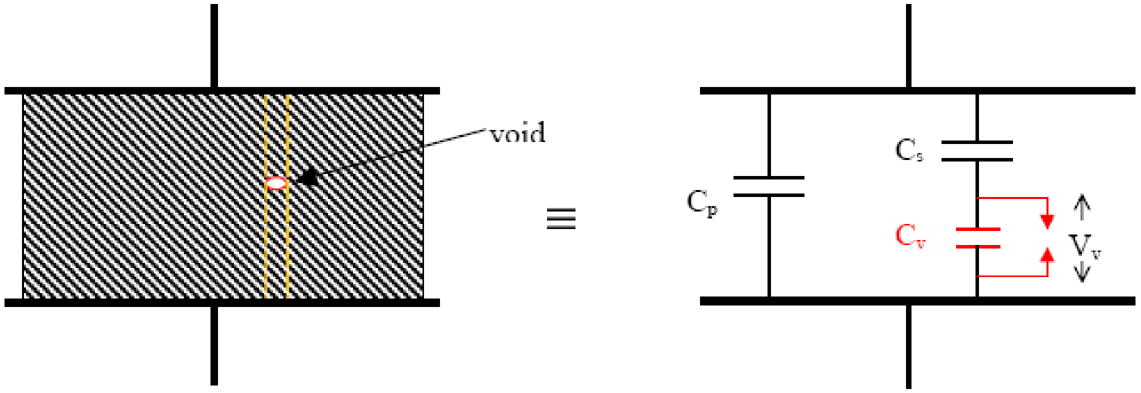
Applied voltage to the sphere gap at 35^0c and 765 torr = 120 x 0.958

= 114.96 kV

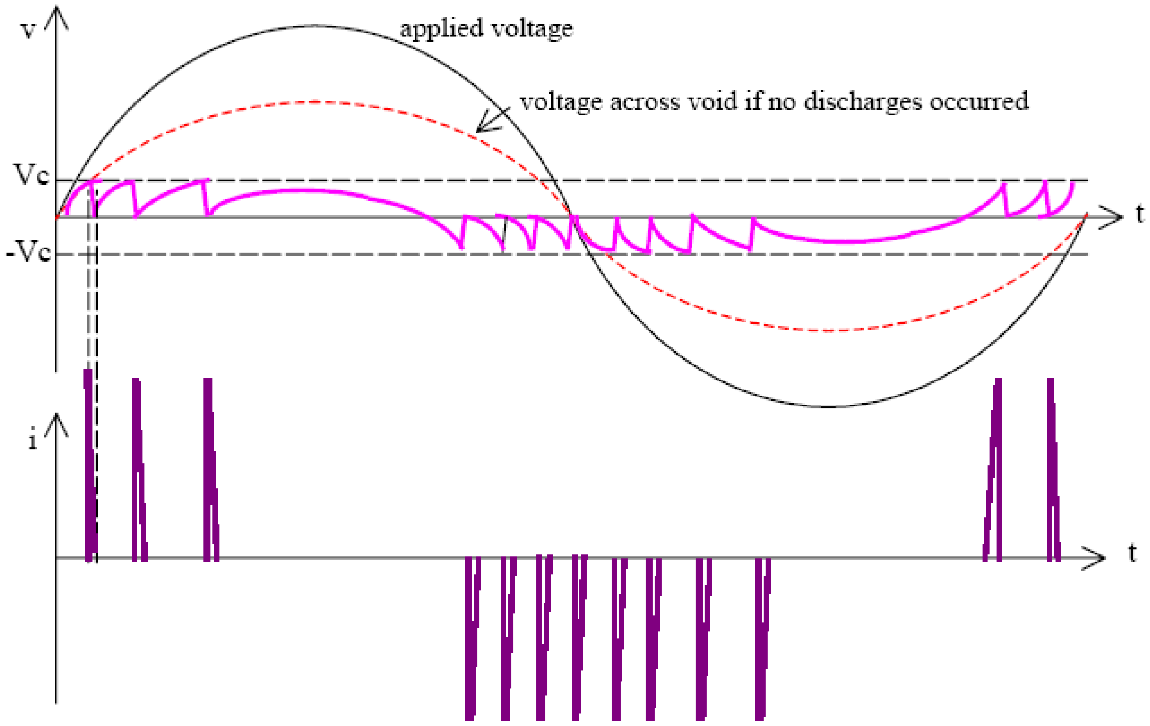
Question 5

(a) Internal discharge phenomenon of a solid dielectric

Solid insulating materials sometimes contain voids or cavities in the medium or boundaries between the dielectric and the electrodes. These voids have a dielectric constant of unity and a lower dielectric strength. Hence the electric field strength in the voids is higher than that across the dielectric. Thus even under normal working voltages, the field in the voids may exceed their breakdown value and breakdown may occur. The mechanism can be explained by considering the following equivalent circuit of the dielectric with the void, shown in figure below,



When the voltage Vv across the void exceeds the critical voltage Vc, a discharge is initiated and the voltage collapses. The discharge extinguishes very rapidly (say 0.1 _s). The voltage across the void again builds up and the discharges recur. The number and frequency of the discharges will depend on the applied voltage. The voltage and current waveforms (exaggerated for clarity) are shown in figure below,

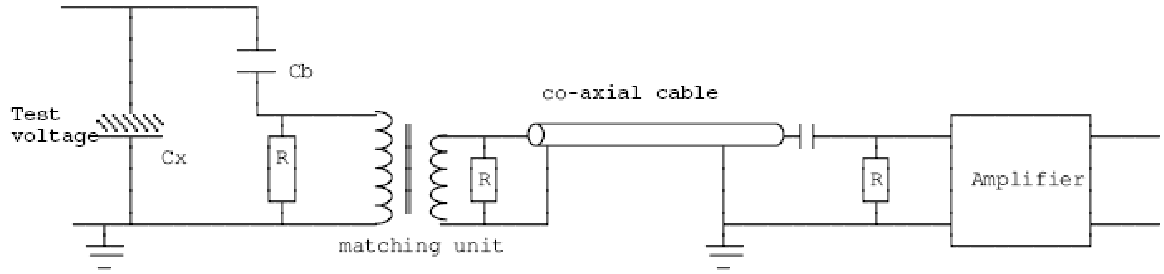


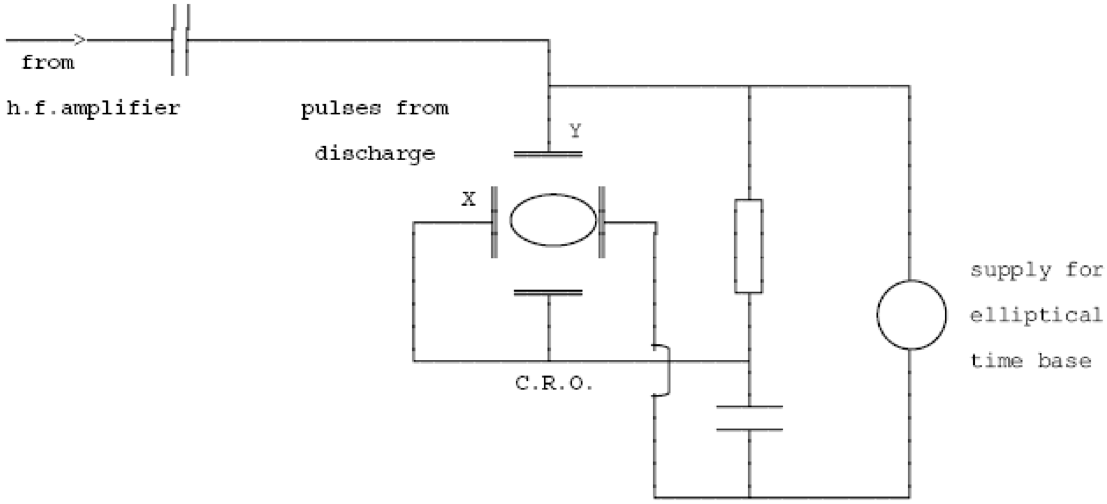
In each of the discharges, there will be heat dissipated in the voids which will cause carbonization of the surface of the voids and erosion of the material. The gradual erosion of the material and consequent reduction in the thickness of the insulating material eventually leads to breakdown. Breakdown by this process is slow and may occur in a few days or may take a few years.

(b) Use of oscilloscope with elliptical time base for the deflection of internal discharges of a solid dielectric

Detection of internal discharges can be carried out by various methods. It can be done by ,visual methods – in transparent insulation the sparks can be detected by either direct observation or by using a photo-electric cell; audible methods - the audible clicks given out by the discharges may be detected by using a microphone, an ultrasonic detector or other transducer; and electrical methods,

In many instances, the detector cannot be used close to equipment, and matching units are employed which permit the use of about 30 m of co-axial lead between detector and the source of discharge. Calibration is done by injection of a known step voltage into the system. This gives direct calibration of discharge amplitude and takes into account the response of the amplifier. The discharge detector input circuit is shown in figure below. The output of the amplifier is displayed on a oscilloscope having an elliptical time base. The time base is produced from a phase shifting R-C network. It is possible to distinguish between several types of discharges from the nature of the output displayed on the oscilloscope.

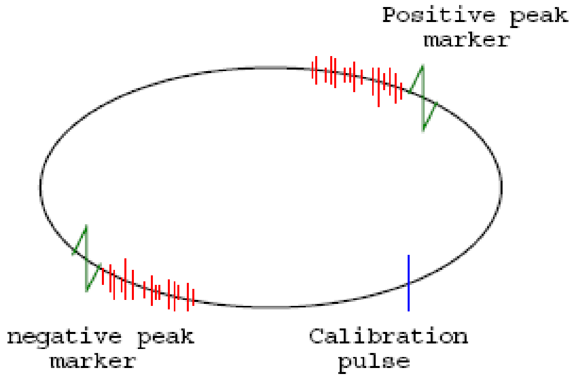




The oscilloscope X and Y plates are supplied from a separate source so as to form an ellipse on the screen. By applying the output from the high frequency amplifier to the Y-plates, we can obtain the high frequency pulse superposed on the ellipse. The height of the pulse can be measured.

Displays on the oscilloscope for some typical discharges are shown in figure below, together with corresponding waveforms arising out of external discharges as well as from contact noise.

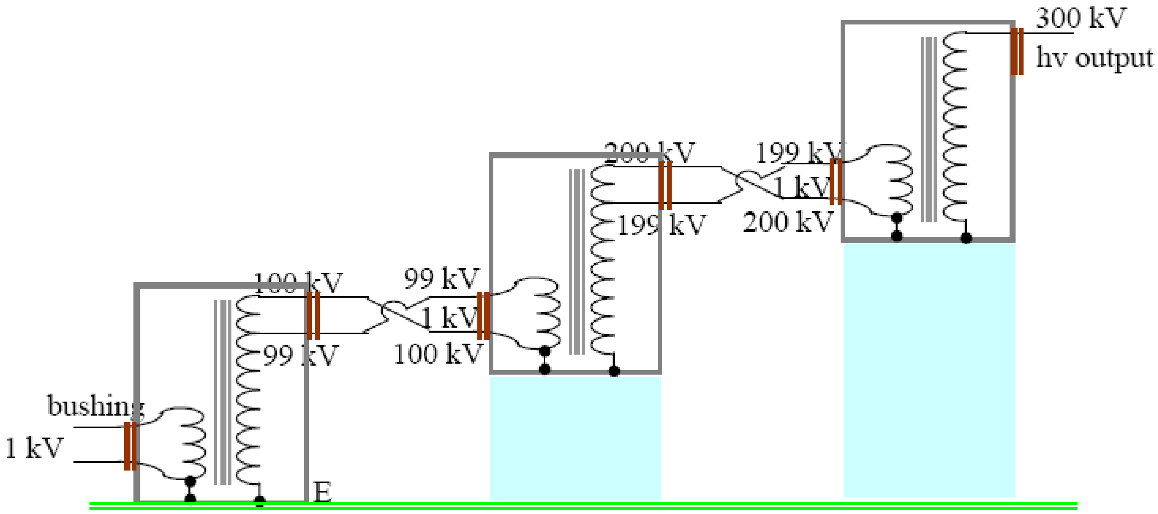
(c) Oscillogram for the internal discharge of an oil impregnated capacitor



The above figure shows a typical oil-impregnated paper capacitor: The discharges are approximately equal in magnitude and numbers in the two half cycles, but have opposite polarity.

(d) Use of cascade arrangement of transformers for generation of high alternating voltages

Single transformer test units are made for high alternating voltages up to about 200 kV. However, for high voltages to reduce the cost (insulation cost increases rapidly with voltage) and make transportation easier, a cascade arrangement of several transformers is used.



The above figure shows a typical cascade arrangement of transformers used to obtain up to 300 kV from three units each rated at 100 kV insulation. The low voltage winding is connected to the primary of the first transformer, and this is connected to the transformer tank which is earthed. One end of the high voltage winding is also earthed through the tank. The high voltage end and a tapping near this end is taken out at the top of the transformer through a bushing, and forms the primary of the second transformer. One end of this winding is connected to the tank of the second transformer to maintain the tank at high voltage. The secondary of this transformer too has one end connected to the tank and at the other end the next cascaded transformer is fed. This cascade arrangement can be continued further if a still higher voltage is required.

In the cascade arrangement shown, each transformer needs only to be insulated for 100 kV, and hence the transformer can be relatively small. If a 300 kV transformer had to be used instead, the size would be massive. High voltage transformers for testing purposes are designed purposely to have a poor regulation. This is to ensure that when the secondary of the transformer is short circuited (as will commonly happen in flash-over tests of insulation), the current would not increase to too high a value and to reduce the cost. In practice, an additional series resistance (commonly a water resistance) is also used in such cases to limit the current and prevent possible damage to the transformer.

What is shown in the cascade transformer arrangement is the basic principle involved. The actual arrangement could be different for practical reasons.