UNIT - 2

Break down phenomenon in Gases & liquids

The simplest and the most commonly found dielectrics are gases. most of the electrical apparatus use air as the insulating medium, and in a few cases other gases such as nitrogen (N_2), carbon dioxide (CO_2), freon (CCl_2F_2) and sulphur hexafluoride (SF_6) are also used.

various phenomena occur in gaseous dielectrics when a voltage is applied. when the applied voltage is low, small currents flow between the electrodes and the insulation retains it electrical properties. on the other hand, if the applied voltages are large, the current flowing through the insulation increases very sharply, and electrical breakdown occurs. A strongly conducting spark formed during breakdown practically produces a short circuit between the electrodes.

The maximum voltage applied to the insulation at the moment of breakdown is called the breakdown voltage

The electrical discharge in gases are two types.

(i) non-sustaining discharges
(ii) self-sustaining discharges

The breakdown in a gas, called spark breakdown is the transition of a non-sustaining discharge into a self sustaining discharge.

The various physical conditions of gases, namely, pressure, temperature, electrod field configuration, nature of electrode surfaces, and the availability of initial conducting particles are known to govern the ionization processes.

Liquids as Insulators:-

Liquid dielectrics, because of their inherent properties, appear as though they would be more useful as insulating materials than either solids or gases. This is because both liquids and solids are usually 10^3 times denser than gases and hence, from Paschen's law it should follow that they possess much higher dielectric strength of the order of 10^7 V/cm. Also, liquids, like gases, fill the complete volume to be insulated and simultaneously will dissipate heat by convection.

-> oil is about 10 times more efficient than air or nitrogen in its heats transfer capability when used in transformer

-> Liquid dielectrics are used mainly as impregnants in high-voltage cables and capacitors, and for filling up of transformers, circuit breakers etc.

-> It acts like heat transfer agent and arc-quenching media in circuit breakers.

-> Petroleum oils (Transformer oil) are the most commonly used liquid dielectric.

-> The presence of even 0.01% water in transformer oil reduces its electrical strength 20% of the dry oil value.

Collision Processes:-

Types of collision:-

These are of the two types.

1. Elastic collisions
2. Inelastic collisions

Elastic collisions:- Elastic collisions are collisions which when occur, no change takes place in the internal energy of the particles but only their kinetic energy get distributed. These collisions do not occurs in practice. When electrons collide with gas molecules, a single electron traces a zig-zag path during its travel. But in between the collisions it is accelerated by the electric field. Since electrons are very light in weight they transfer only a part of their kinetic energy to the much heavier ions or gas molecules with which they collide.

This result in very little loss of energy by the electrons and therefore electrons gain very high energies and travel at a much higher speed than the ions.

Inelastic collisions:-

Inelastic collisions, on the other hand, are those in which internal changes in energy take place within an atom or a molecule at the expense of the total kinetic energy of the colliding particle. The collision often results in a change in the structure of the atom.

Thus all collisions that occur in practice are inelastic collions.

Ex: ionisation, attachment, excitation, recombination.

Mobility of Ions & Electrons:-

When an ion moves through a gas under the influence of a static uniform electric field, it gains energy from the field between collisions and loses energy during collisions.

Electric force on an electron/ion of charge 'e' is eE, with the resulting acceleration being eE/m. When the energy gained by the ions from the electric field is small compared with the thermal energy, the drift velocity in the field direction ω_i is proportional to the electrical field intensity E and may be expressed as follows:

$$\omega_i = \mu_i E$$

μ_i is called the mobility of ions.

Diffusion coefficient:-

When particles possessing energy, which is exhibited as a random motion, are distributed unevenly throught a space, then they tend to redistribute themselves uniformly throughtly the space. This process is known as diffusion and the rate at which this occurrence is governed by the diffusion passing through unit area in unit time perpendicular to the concentration gradient and for unit concentration gradient.

In three dimensions this may be written as

$$\frac{\partial n}{\partial t} = D \nabla^2 n$$

D is diffusion coefficient

$$D = 1/3(lc)$$

l = mean free path

c = random velocity.

Electron energy Distributions:-

For the development of a complete theory giving the relationship between the data concerning single collisions of electrons with gas molecules, and the experimentally obtained average properties of discharges, a knowledge of the electron energy distribution function is essential

collision cross section:-

collision cross section is defined as the area of contact between two particles during a collisions, in other words, the total area of impact.

If Q_t is the total cross section, and $Q_i, Q_e, Q_c \cdots$ etc. are the cross section for ionization, excitation, charge transfer etc.

Then

$$Q_t = Q_i + Q_e + Q_c + \cdots$$

The probability of collisions take place

i.e $P = nQ$.

The mean free path (λ):-

The mean free path is defined as the average distance between collisions. when a discharge occurs large number of collisions occur between the electrons and the gas molecules. Depending upon the initial energy of the colliding electron, the distance between the two collisions vary. The average of this is the mean free path. It is an random quantity.

'λ' is very high for low pressure
'λ' is very small for high pressure

The mean free path

$$\lambda = K/P \text{ cm.}$$

'K' is constant
'P' is pressure in microns

'K' for nitrogen is '5'
'P' " 10^{-6} torr.

Ionization Processes:-

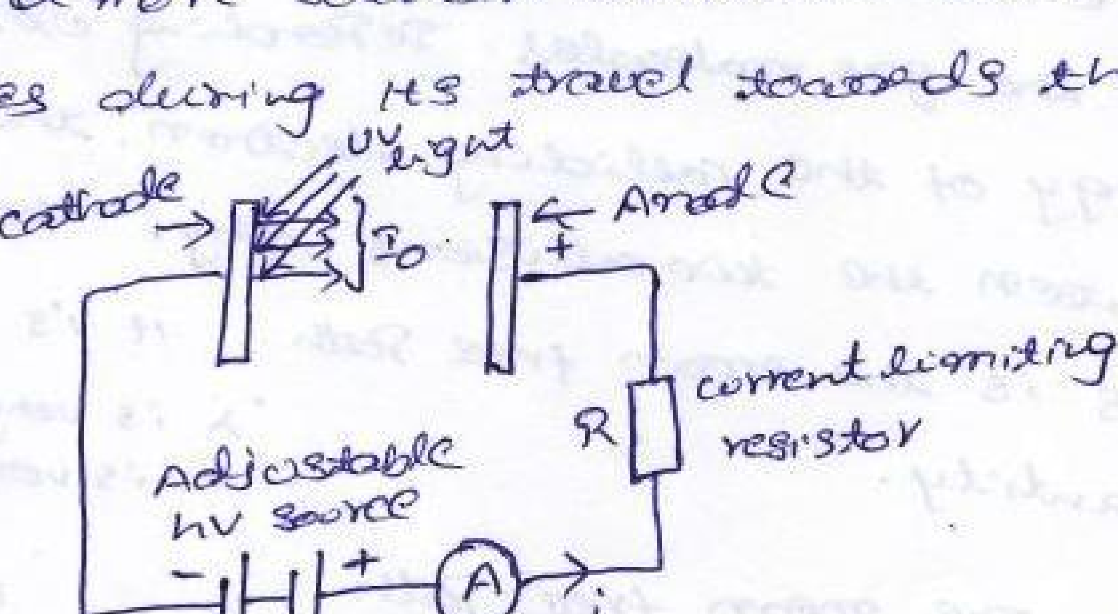
A gas in its normal state is almost a perfect insulator. However, when a high-voltage is applied between the two electrodes immersed in a gaseous medium, the gas becomes a conductor and an electrical breakdown occurs.

The Processes that are primarily responsible for the breakdown of gas are Ionization by collision, photo-ionization, and the secondary ionization processes.

Ionization by collision:-

The process of liberating an electron from a gas molecule with the simultaneous production of a positive ion called ionization. In the process of ionization by collision, a free electron collides with a neutral gas molecule and gives rise to a new electron and a positive ion.

If we consider low-pressure gas column in which an Electric field 'E' is applied across two plane parallel electrodes, as shown in below diagram. then, any electron starting at the cathode will be accelerated more and more between collisions with other gas molecules during its travel towards the anode.



If the energy (E) gained during this travel between collisions exceeds the ionization potential V_i which is the energy required to dislodge an electron from its atomic shell, the ionization takes place. This process can be represented as

$$e^- + A \xrightarrow{eV_i} e^- + A^+ + e^-$$

A → is atom A^+ → +ve Ion

e^- → electron.

A few of the electrons produced at the cathode by some external means, say by ultra-violet light falling on the cathode, ionize neutral gas particles producing +ve ions and additional electrons. The additional electrons, then, themselves make 'ionizing collisions' and thus the process repeats itself. This represents an increase in the electron current, since the number of electrons reaching the anode per unit time is greater than those liberated at the cathode. In addition, the +ve ions also reaches the cathode and on bombardment on the cathode give rise to secondary electron

Photo Ionization:-

The phenomena associated with ionization by radiation or photo-ionization, involves the interaction of radiation with matter. Photo-ionization occurs when the amount of radiation energy absorbed by an atom or molecule exceeds its ionization potential.

There are several processes by which radiation can be absorbed by atoms or molecules. They are

(a) excitation of the atom to a higher energy state, and

(b) continuous absorption by direct excitation of the atom or dissociation of diatomic molecule or direct ionization etc.

Just as an atom emits radiation when the atom electron returns to the lower state or to the ground state, the reverse process takes place when an atom absorbs radiation

$$h\nu + A \rightleftarrows A^*$$

Ionization occurs when

$$\lambda \leq c \cdot \frac{h}{V_i}$$

'h' Planks constant

'c' velocity of light

'λ' wave length of the radiation

'V_i' Ionization energy of the atom.

substitute h & c we get

$$\lambda \leq \left(\frac{1.27}{V_i}\right) \times 10^{-6} cm$$

V_i : electron volts = (eV)

The higher the ionization energy, the shorter will be the wavelength of radiation capable of causing ionization. It was observed experimentally that a radiation having a wavelength of 1250 Å is capable of causing photo-ionization of almost all gases.

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 ionization by collision and photo-ionization.

They are briefly described below.

a) Electron Emission due to Positive Ion Impact:-

Positive ions are formed due to ionization by collision or by photo-ionization, and being positively charged, they travel towards the cathode.

A +ve 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 +ve ion, namely, the sum of its kinetic energy and the ionization energy, is greater than twice the work function of the metal, then an electron will be ejected and a second electron will neutralise the ion. The probability of this prosses is measured & which is called the Townsend's secondary ionization coefficent.

b) Electron Emission due to Photons:-

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

$$h \cdot \nu \leq \varphi$$

$\varphi \rightarrow$ work function of metallic electrode.

The frequency (ν) is $= \frac{\varphi}{h}$.

for nickel surface $\varphi = 4.5\,eV$

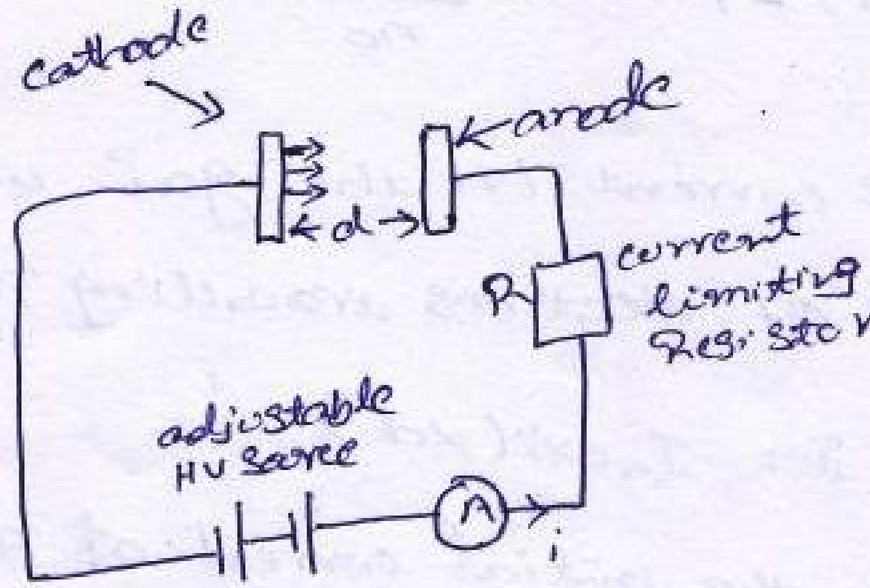
$\lambda = 2755\,Å$

c) Electron emission due to metastable and neutral atoms:

A metastable atom or molecule is an excited particle whose lifetime is very large (10^{-3} sec) compared to the lifetime of an ordinary particle (10^{-8} s). 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 absorved with metastable atoms, because the life time of the other excited states is too short for reaching the cathode and cause electron emission.

Neutral atoms in ground state also give rise to secondary emission if their kinetic energy is high (≈ 1000 eV).

TOWNSEND's current growth equation:-



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 centimetere travel in the direction of the field (α depends on gas Pressure P & 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.

$$dn_x = \alpha n_x dx \quad - (1)$$

$x = 0 \quad n_x = n_0$ (electrons emitted at cathode)

from (1)

$$\frac{dn_x}{dx} = \alpha n_x \quad (or) \quad n_x = n_0 \exp(\alpha x)$$

Then no. of electrons reaching the anode $x = d$

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

The no. of new electrons created, on the average, by each electron is

$$n_d - n_0 = n_0 \exp(\alpha d) - n_0$$

$$\exp(\alpha d) - 1 = \frac{n_d - n_0}{n_0}$$

∴ The average current in the gap, which is equal to the number of electrons travelling per second will be $I = I_0 \exp(\alpha d)$

I_0 is the initial current at cathode.

Current growth in the presence of secondary processes:-

The single avalanche process described in the previous section becomes complete when the initial set of electrons reaches the anode. However, since the amplification of electrons [$\exp(\alpha d)$] 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.

- → The +ve ions liberated may have sufficient energy to cause liberation of electrons from the cathode when they impinge on it.
- → The excited atoms or molecules in avalanches may emit photons, and this will lead to the emission of electrons due to photo-emission.
- → The metastable particles may diffuse back causing electron emission.

The electrons produced by these processes are called secondary electrons. The secondary ionization coefficient 'γ' is defined in the same way as 'α',