Presentation On

Breakdown In Gases

Presentation By
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Gases as insulating media

- **Gases**

- The simplest and the most commonly dielectrics.
- Dielectric v/s Insulator materials
- Most of the electrical apparatus use air as the insulating medium. Ex. nitrogen , carbon dioxide, Freon ,and sulphur hexafluoride (SF_6).
- *The maximum voltage applied to the insulation at the moment of breakdown is called the breakdown voltage.*
- The build-up of high currents in a breakdown is due to the process known as ionization in which electrons and ions are created from neutral atoms or molecules, and their migration to the anode and cathode respectively leads to high currents.

Ionization Process

- *The process of liberating an electron from a gas molecule with the simultaneous production of a positive ion is called ionisation.*

- *A free electron collides with a neutral gas molecule and gives rise to a new electron and a positive ion is called ionization by collision.*

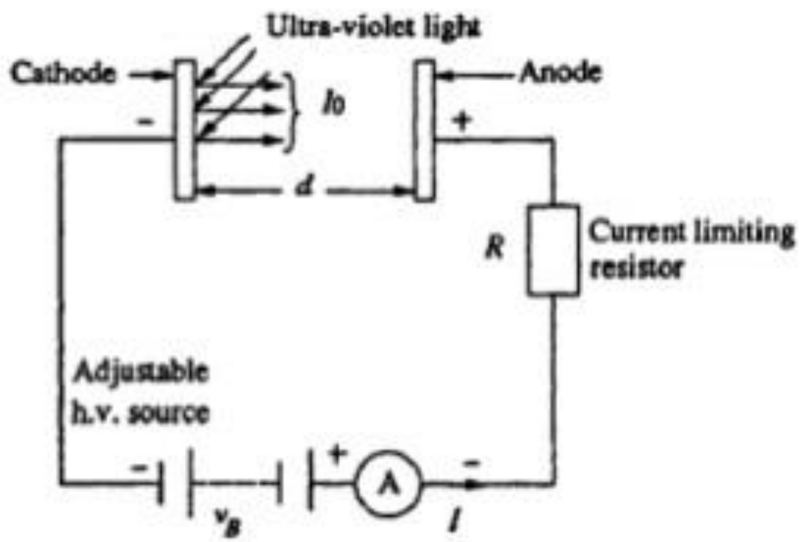


Fig. 2.1 Arrangement for study of a Townsend discharge

Ionization by collision

- If electric field E is applied to two plane parallel electrodes
- 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 ionisation potential, *Vi* (*energy required to dislodge an electron from its atomic shell*) then ionisation takes place.

$$e^- + A \xrightarrow{\varepsilon > V_i} e^- + A^+ + e^-$$

Where, A is the atom, A^+ is the positive ion and e^- is the electron.

Ionization by collision

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

Photo-ionisation

- The phenomena associated with ionisation by radiation, or photo-ionisation, involves the interaction of radiation with matter.

- Photo-ionisation occurs when the amount of radiation energy absorbed by an atom or molecule exceeds its ionisation potential.

- an excited atom emits radiation when the electron returns to the lower state or to the ground state, the reverse process takes place when an atom absorbs radiation.

- $$hv + A \rightleftharpoons A^*$$

- Ionisation occurs when :

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

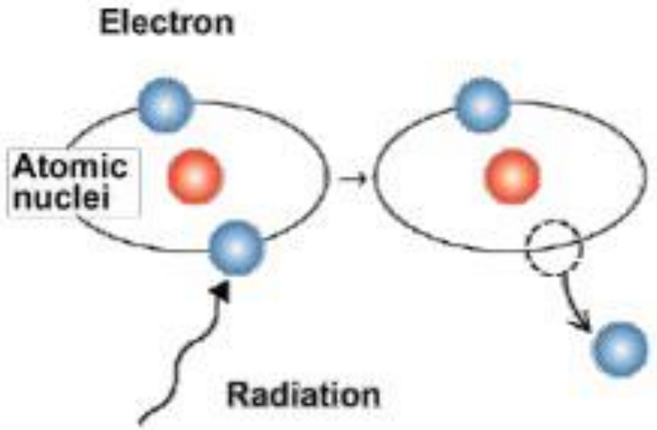


Photo-ionisation

- ***h*** is the Planck's constant, ***c*** is the velocity of light, λ is the wavelength of the incident radiation and ***Vi*** is the ionisation energy (eV) of the atom.
- Substituting for ***h*** *and* **c**, we get:

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

- The higher the ionisation energy, the shorter will be the wavelength of the radiation capable of causing ionisation.

- It was observed experimentally that a radiation having a wavelength of 1250 $A°$ *is capable of causing* photo-ionisation of almost all gases.

Secondary Ionisation Processes

1. **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 = kinetic energy + 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 ionisation coefficient

Secondary Ionisation Processes

2. Electron Emission due to Photons:

- To cause the electron to escape from metal, it should be given enough energy to overcome the surface potential barrier.

- The energy can supplied in the form of a photon of ultraviolet light of suitable frequency.

- Electron emission from a metal surface occurs at the condition of :

$$h \cdot v \geq \phi$$

- The frequency (v) is given by the relationship: $v = \frac{\phi}{h}$
  v is the threshold frequency

- If the incident radiation has a greater frequency than the threshold frequency, the excess energy goes partly as the kinetic energy of the emitted electron and partly to heat the surface of the electrode

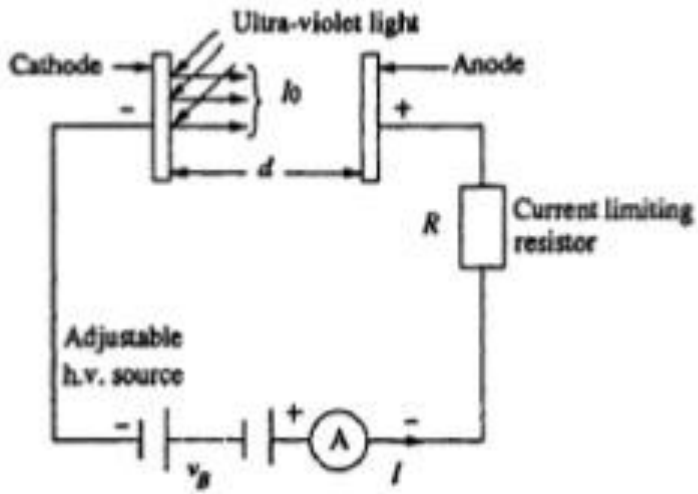
Secondary Ionisation Processes

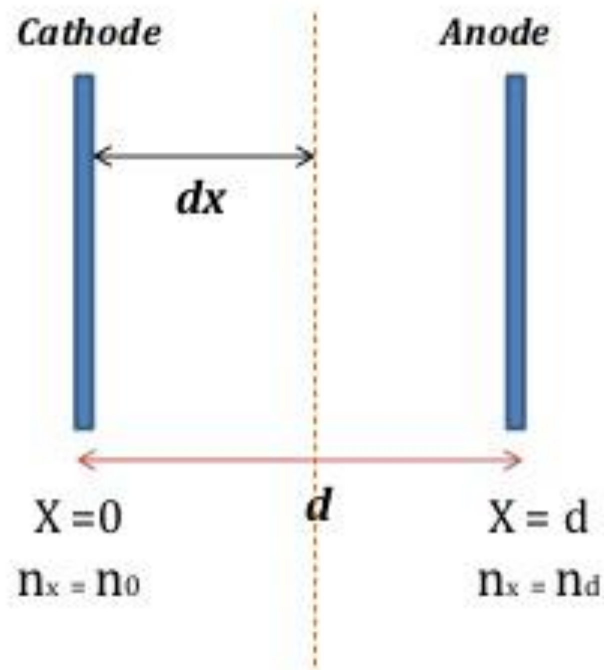
3. Electron Emission due to Metastable and Neutral Atoms :

- A metastable atom or molecule is an excited particle whose lifetime is very large (10^{-3} s) 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 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.
- 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).

TOWNSEND'S CURRENT GROWTH EQUATION

- 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.



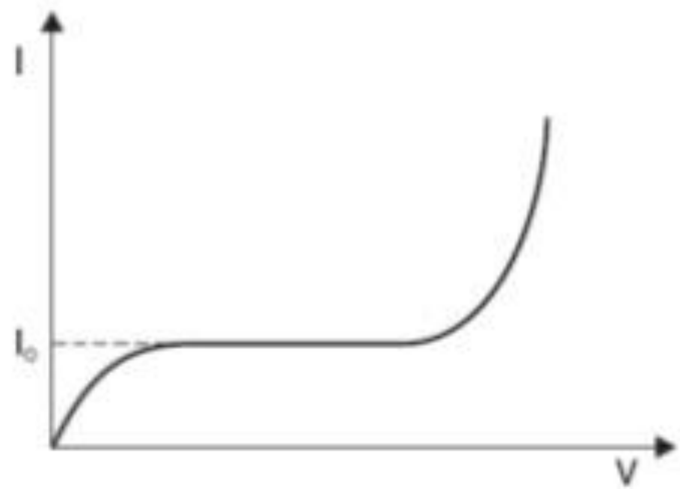


- At any distance **x** from the cathode, let the number of electrons be n_x.

TOWNSEND'S CURRENT GROWTH EQUATION

- The variation of current as a function of voltage was studied by Townsend. He found that the current at first increased proportionally as the voltage is increased and then remains constant.

- At still higher voltages, the current increases exponentially.



- The exponential increase in current is due to ionization of gas by electron collision.

TOWNSEND'S CURRENT GROWTH EQUATION

- The variation of current as a function of voltage was studied by Townsend. He found that the current at first increased proportionally as the voltage is increased and then remains constant.
- As the voltage increases V/d increases and hence the electrons are accelerated more and more and between collisions these acquire higher kinetic energy and, therefore, knock out more and more electrons.
- To explain the exponential rise in current, Townsend introduced a coefficient α known as *Townsend's first ionization coefficient*
- *α = the number of electrons produced by an electron per unit length of path in the direction of field.*

TOWNSEND'S CURRENT GROWTH EQUATION

- 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.

- At any distance **x** from the cathode, let the number of electrons be n_x. The rate of flow of electrons (i.e current) can be written by:

$$dn_x = n_x \cdot \alpha \cdot dx$$

$$\int \frac{dn_x}{n_x} = \int \alpha \cdot dx$$

$$\ln n_x = \alpha \cdot x + A$$

TOWNSEND'S CURRENT GROWTH EQUATION

- At $x = 0$, $n_x = n_0$

$$\ln n_0 = 0 + A$$

$$\therefore A = \ln n_0$$

$$\therefore \ln n_x = \alpha \cdot x + \ln n_0$$

$$\ln n_x - \ln n_0 = \alpha \cdot x$$

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

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

- No of electron reaching the anode ***x=d*** will be

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

TOWNSEND'S CURRENT GROWTH EQUATION

- Average current in the gap is equal to no of electron travelling per second:
- $$I_d = I_0 e^{\alpha \cdot d}$$ ………………………………………..(1)

I_0 = Initial current at cathode
$e^{\alpha d}$ = electron avalanche

- It represents no of electron produced by the one electron travelling from cathode to anode.

- Equation 1 is called *Townsends current growth equation due to primary ionization coefficient α*.

TOWNSEND SECOND IONISATION COEFFICIENT

- Townsend in his earlier investigations had observed that the current in parallel plate gap increased more rapidly with increase in voltage as compared to the one given by the previous equation.

- Townsend suggested that a second mechanism must be affecting the current. He postulated that the additional current must be due to the presence of positive ions and the photons.

- The positive ions will liberate electrons by collision with gas molecules and by bombardment against the cathode. Similarly, the photons will also release electrons after collision with gas molecules and from the cathode after photon impact.

TOWNSEND SECOND IONISATION COEFFICIENT

- Let, **n** be the number of electrons released from the cathode by ultraviolet radiation.
- n_+ the number of electrons released from the cathode due to positive ion bombardment.
- n_d *the number of* electrons reaching the anode.
- Let γ, known as *Townsend second ionization co-efficient be defined as* the number of electrons released from cathode per incident positive ion.
- Then,

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

$$n_d = (n_0 + n_+) e^{\alpha \cdot x}$$

TOWNSEND SECOND IONISATION COEFFICIENT

- Now total number of electrons released from the cathode is **($n + n_+$)** *and those reaching the* anode are n_d.

- the number of electrons released from the gas = $n-(n + n_+)$, and corresponding to each electron released from the gas there will be one positive ion and assuming each positive ion releases γ effective electrons from the cathode then.

We have equation from Townsends primary ionization as

$$n_d = n_o e^{\alpha d} \quad ...(1)$$

The equation changes to

$$n_d = (n + n_+) e^{\alpha d} \quad ...(2)$$

Here $n_o + n_+$ – are the number of electrons at the cathode

$$n_+ = (\text{additional electron})\, \gamma$$

$$n_+ = [n_d - (n + n_+)]\, \gamma \quad ...(3)$$

TOWNSEND SECOND IONISATION COEFFICIENT

$$n_+ = n_d \cdot \gamma - n_0 \cdot \gamma - n_+ . \gamma$$

$$n_+ + n + \gamma = n_d \cdot \gamma - n_0 \cdot \gamma$$

$$n_+ (1 + \gamma) = n_d \cdot \gamma - n_0 \cdot \gamma$$

$$n_+ = \frac{\gamma (n_d - n_0)}{(1 + \gamma)}$$

Put value of n_+ in (2)

$$n_d = \left[n_0 + \frac{\gamma (n_d - n_0)}{(1 + \gamma)} \right] e^{\alpha d}$$

$$= \left[\frac{n_0 + n_0 \cdot \gamma + n_d \cdot \gamma - n_0 \cdot \gamma}{(1 + \gamma)} \right] e^{\alpha d}$$

$$n_d = \left[\frac{n_0 + n_d \cdot \gamma}{(1 + \gamma)} \right] e^{\alpha d}$$

TOWNSEND SECOND IONISATION COEFFICIENT

$$n_d + n_d \cdot \gamma = n_0 \cdot e^{\alpha d} + n_d \cdot \gamma \cdot e^{\alpha d}$$

$$n_d + n_d \cdot \gamma - n_d \cdot \gamma \cdot e^{\alpha d} = n\, e^{\alpha d}$$

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

$$n_d = \frac{n_0 \cdot e^{\alpha d}}{[1 + \gamma (1 - e^{\alpha d})]}$$

Divide by time.

$$\frac{n_d}{t} = \frac{n_0 \cdot e^{\alpha d}}{[1 + \gamma (1 - e^{\alpha d})]} / t$$

$$\therefore I = \frac{I_0\, e^{\alpha d}}{1 - \gamma (e^{\alpha d} - 1)} \quad \ldots \text{(I)}$$

This is Townsends current grown equation due to primary (α) and secondary (γ) ionization.

TOWNSEND BREAKDOWN MECHANISM

- When voltage between the anode and cathode is increased, the current at the anode is given by·

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

The current becomes infinite if

$$1 - \nu(e^{\alpha d} - 1) = 0$$

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

or $$\nu e^{\alpha d} = 1$$

Since normally $$e^{\alpha d} >> 1$$

- the current in the anode equals the current in the external circuit. Theoretically the current becomes infinitely large under the above mentioned condition but practically it is limited by the resistance of the external circuit.
- The condition $\nu e^{\alpha d} = 1$ *defines the condition* for beginning of spark and is known as the *Townsend criterion for spark formation or Townsend breakdown* criterion.

STREAMER OR KANAL MECHANISM OF SPARK

- Streamer theory postulated by Reather and Meak removes the limitations and drawbacks of townsend's theory.

- *According to the townsend's theory, electric spark discharge is due to the ionization of gas molecule by the collision of electron and release of electron from cathode due to positive ion bombardment.*

- But according to the streamer's theory, It is not only ionization process responsible for breakdown of gas but such as formation of photon and space charge into the avalanche also are root cause of breakdown.

- Reather explains the formation of spark due to streamer mechanism in which the secondary mechanism of photo ionization of gas molecule is involved.

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