Conduction in liquids and Gases

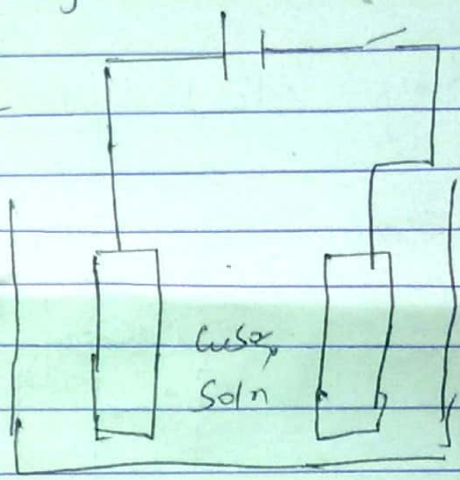
- Solid
  - Conductor
  - Insulator
- liquid
  - Electrolyte
  - Non-electro

Gas

high p.d (voltage) → discharge
reducing pressure

Electrical conduction in liquid

$CuSO_4 \rightarrow Cu^{++} + SO_4^{--}$



Initially, when electric field is applied through liquid dielectric there is no current. As we go on increasing electric field the impurity, air or liquid get discharged giving ~~can~~ small current

When electric field strength is large enough we get large amount of current suddenly and the liquid acts as conducting medium. The voltage acts on this system is called breakdown voltage. This phenomenon is called Electric breakdown in liquid.

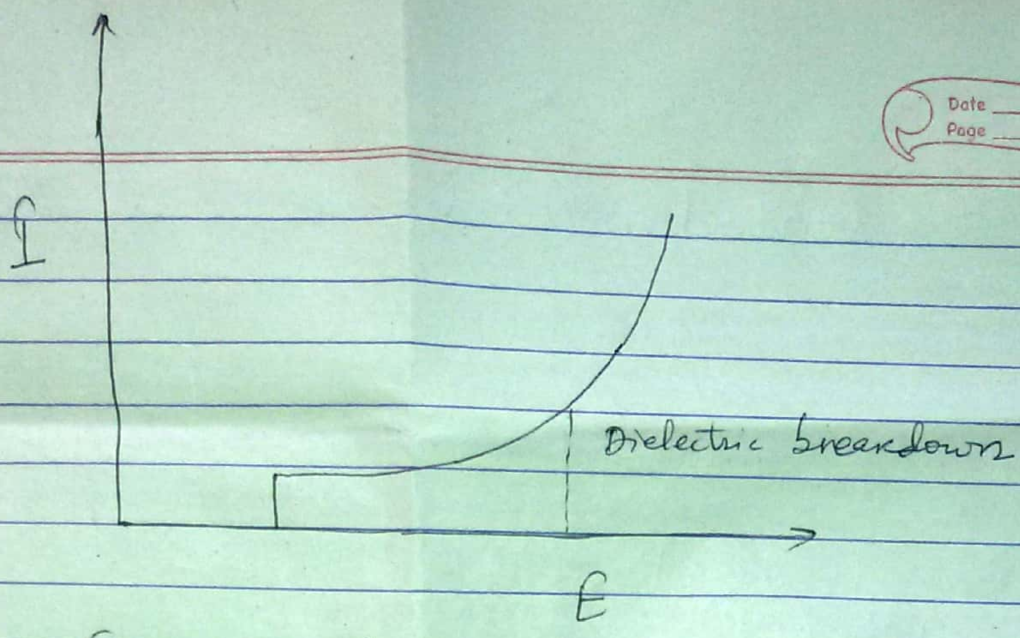
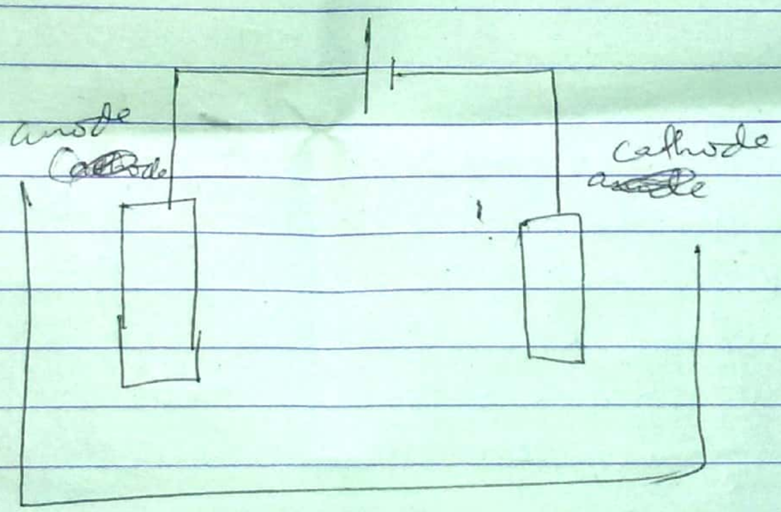


Fig: Conduction Current versus electric field

Eg: Electrolysis or electroplating



$CuSO_4 \longrightarrow Cu^{++} + SO_4^{--}$

+vely charged cations moves towards cathod &
-vely " anion " " anode

Date
Page

The ionic conductivity is given by

$$\sigma = ne\mu \quad \text{--- (1)}$$

$n \rightarrow$ no of ions $\mu \rightarrow$ mobility of ions

from Einstein relation

$$\frac{D}{\mu} = \frac{KT}{e} \Rightarrow \mu = \frac{eD}{KT} \quad \text{--- (2)}$$

The diffusion coefficient varies with tempr

$$D = D_0 e^{-\frac{Q}{KT}} \quad \text{---- (3)}$$

from (1) & (2)

$$\sigma = ne\frac{eD}{KT}$$

$$\sigma = ne\frac{e}{KT}D_0 e^{-\frac{Q}{KT}}$$

$$\sigma = \frac{ne^2 D_0}{KT} e^{-\frac{Q}{KT}}$$

$$\sigma = \sigma_0 e^{-Q/KT} \quad \sigma_0 = \frac{ne^2 D_0}{KT}$$

taking ln both sides

$$\boxed{\ln\sigma = \ln\sigma_0 - \frac{Q}{KT}}$$

The relation shows that ionic conductivity depends inversely on tempr

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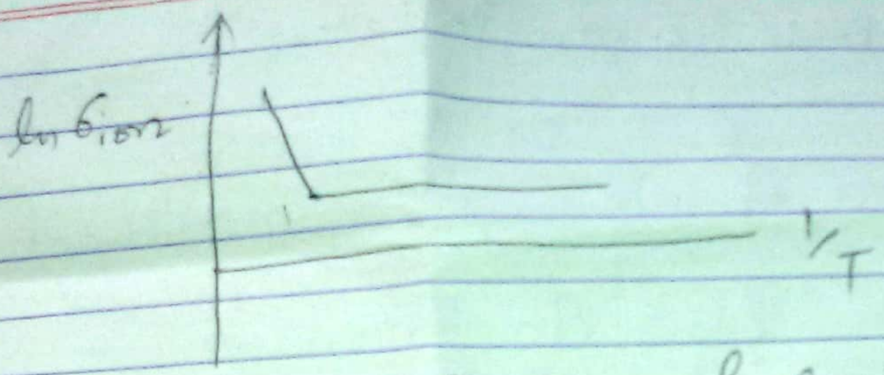
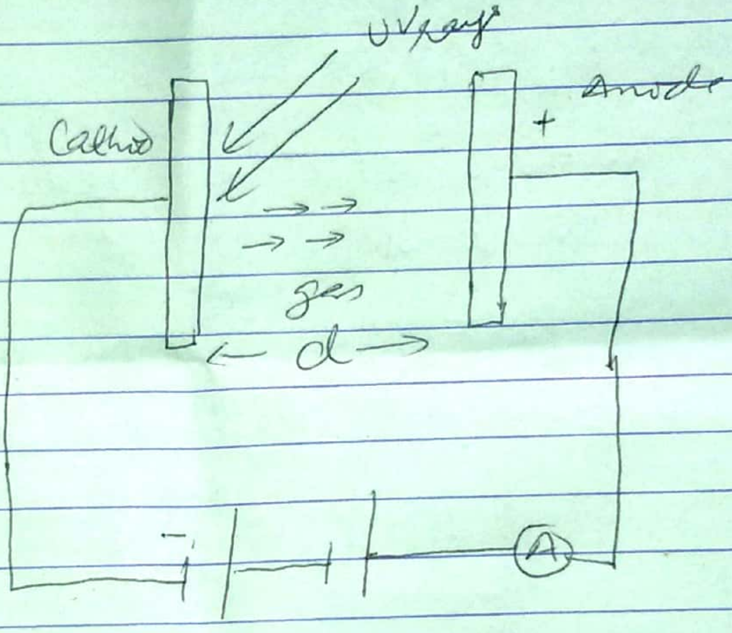


fig. Dependence of ionic conductivity with inverse of tempr.

Electric conduction in Gases

Gas in normal state is almost perfect insulator, However when high p.d. (voltage) is applied between two electrodes in Gas medium, the electric breakdown occurs and the gas becomes a conductor. The maximum voltage applied at the time of electrical breakdown is called breakdown voltage.



Let n_0 be the no. of electrons produced by UV radiation incident on cathode.

n_x be the no. of electrons at a distance x from cathode.

Then

Concentration gradient is proportional to corresponding no. of electrons produced

i.e. $$\frac{dn_x}{dx} \propto n_x$$

$$\frac{dn_x}{dx} = \alpha n_x \quad \text{—— (1)}$$

α is average ionizing collision made by electrons per cm called Townsend's first ionization coefficient

Townsend discharge Mechanism

The Townsend discharge is a gas ionization process where the free electrons are accelerated by an electric field.
The electric field is applied across a gaseous medium, initial ions are created with ionizing radiation (Eg uv rays). An ~~ionization~~ original ionization event produces an ion pair
+ve ion accelerates towards cathode
while free electron " " anode
If the electric field is strong enough, the free electron can gain sufficient energy to librete another electron when it next collides with a molecule.
The excited atom or molecule during discharge of gas may return back to metastable state by emission of photon and this leads to the emission of electrons due to photo emission
These photons & electrons are responsible for further ionization of gas atom & to carry avalanch of ions which results the breakdown in gases and huge current is produced.

Let n_0 be the primary electrons
n_0' " " secondary " produced due to secondary process.
& n_0'' be total no. of electrons leaving cathode

$$n_0'' = n_0 + n_0'$$

The total no. of electrons reaching the anode

$$n = n_0'' e^{\alpha d} = (n_0 + n_0') e^{\alpha d} \qquad (1)$$

$\frac{dn_x}{n_x} = \alpha\, dx$

on integrating

$\int \frac{dn_x}{n_x} = \ln(n_x) = \alpha x + c$

when $x = 0$ $n_x = n_0$ $\Rightarrow C = \ln(n_0)$

$\ln(n_x) = \alpha x + \ln(n_0)$

$\Rightarrow \ln\left(\frac{n_x}{n_0}\right) = \alpha x$

$n_x = n e^{\alpha x}$ ⟵ (2)

the no. of electrons reaching at anode i.e. $x = d$ will be

$n_d = n e^{\alpha d}$ ⟵ (3)

The current produced by those electrons is

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

Where I_0 is initial current at cathode.

Γ

The secondary electrons produced by Secondary process in terms of Townsend secondary ionization coefficient Γ as

γ - gam

$$n_0' = \Gamma(n - n_0'')$$

$$n_0' = \Gamma(n - n_0 - n_0')$$

$$n_0' + \Gamma n_0' = \gamma(n - n_0)$$

$$n_0' = \frac{\gamma(n-n_0)}{1+\gamma} \quad \text{—— (2)}$$

Eqn (1) becomes

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

$$n = \left(\frac{n_0 + \cancel{n_0\gamma} + n\gamma - \cancel{n_0\gamma}}{1+\gamma}\right) e^{\alpha d}$$

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

$$n + n\gamma - n\gamma e^{\alpha d} = n_0 e^{\alpha d}$$

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

$$n = \frac{n_0 e^{\alpha d}}{1-\gamma(e^{\alpha d}-1)} \quad \text{---- (3)}$$

∴ Current produced due to this number of electrons reaching at anode is

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$$I = \frac{I_0 e^{\alpha d}}{1 - r(e^{\alpha d} - 1)} \quad \text{--- (4)}$$

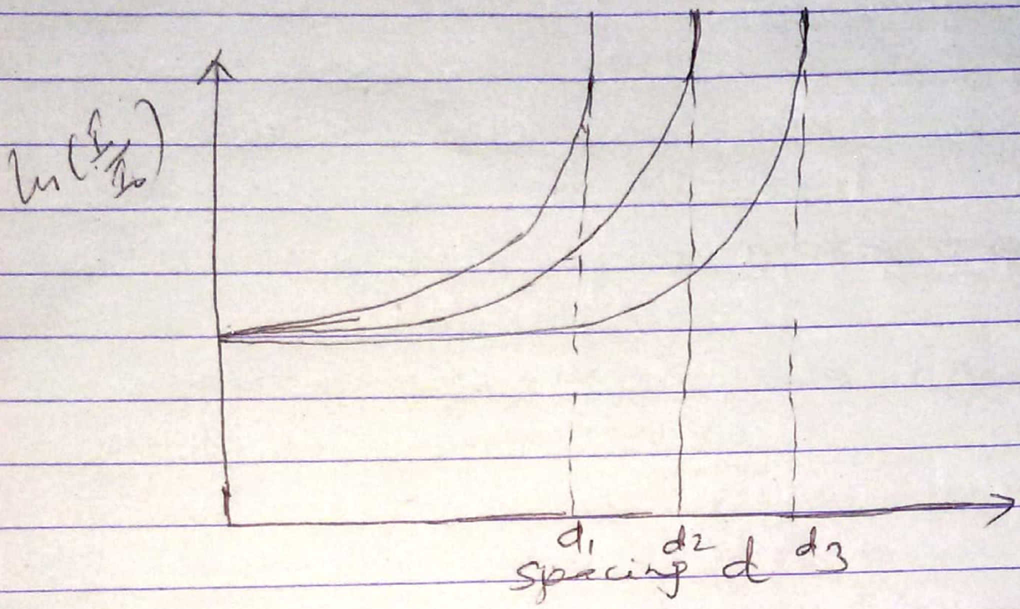

Fig: Growth of current in Townsend discharge