chap: 3 [Conduction in liquid & gases]

EEM

1.

## Conduction in liquid and gases

In certain special cases, we are forced to use liquids and gases to ensure the conduction process takes place smoothly as demanded by the special case. There may be such special cases, where the same material is meant for dual purposes, firstly act as insulation and then during special condition, act as conducting medium.

## Ionic conduction in liquids

The practical aspect of ionic conduction in electrolytes can be visualized from the examples purposely done electrolysis electroplating electrolysis of water and naturally occuring phenomena.

In case of purposely done electrolysis or electroplating, what ~~see~~ we do is to take aqueous media containing the metal to be plated in which two electrodes called cathode and anode are placed. When an external potential is applied, cation and anion are formed, and cation is attracted towards anode while the anion goes towards cathode.

One of the examples of ionic conduction in liquids is electroplating in which the following reaction takes place.

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

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$Cu^{++}$ goes to anode looses positive charge and sticks on to the anode.

$SO_4^{--}$ goes to cathode which is made up of copper, so knocks copper to form $CuSO_4$ in solution making the concentration same as before

The main conduction is caused due to movement of such positively or negatively ion in particular direction on application of electric field. The ionic conductivity is given by,

$$\boxed{\sigma_{ionic} = e N_{ion} \mu_{ion}} \quad \text{—(I)}$$

where, $N_{ion}$ is the number of ions, which are ionised, and moving under the influence of applied electric field and $\mu_{ion}$ is the mobility of these ions;

From Einstein diffusion relation, we have,

$$\boxed{\mu_{ion} = \frac{eD}{kT}} \quad \text{—(II)}$$

where, $D$ is the diffusion coefficient for ion, $k$ is Boltzmann's constant and $T$ is the temperature of the liquid.

The diffusion coefficient varies with temperature as,

$$D = D_0 \exp\left(-\frac{Q}{kT}\right) \quad \text{--- (iii)}$$

Where, $Q$ is the activation energy for the purpose under consideration and $D_0$ is the pre-exponential factor which depends on the vibrational frequency of the atoms and other material properties.

Now, the ionic conductivity can be expressed as,

$$\sigma_{ion} = e N_{ion} \mu_{ion}$$

$$= e N_{ion} \frac{eD}{kT}$$

$$= e N_{ion} \frac{e}{kT} D_0 \exp\left(-\frac{Q}{kT}\right) \quad \text{[From eq}^n\text{s (i), (ii) \& (iii)]}$$

$$= \frac{e^2}{kT} N_{ion} D_0 \exp\left(-\frac{Q}{kT}\right)$$

$$\boxed{\sigma_{ion} = \sigma_0 \exp\left(-\frac{Q}{kT}\right)} \quad \text{--- (iv)}$$

$$\text{Where, } \sigma_0 = \frac{e^2 N_{ion} D_0}{kT} \quad \text{--- (v)}$$

Taking natural logarithm on both the sides, we get;

$$\boxed{\ln \sigma_{ion} = \ln \sigma_0 - \frac{Q}{kT} = \ln \sigma_0 - \left(\frac{Q}{k}\right)\frac{1}{T}} \quad \text{--- (vi)}$$

From the above equation (VI), it is concluded that the ionic conductivity is inversely proportional to the temperature.

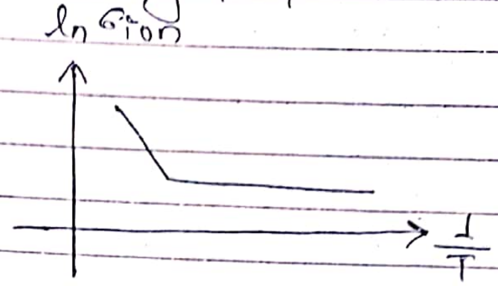


Fig: Dependence of ionic conductivity to the temperature.

* Electrical conduction in gases

Gases are very easily available in the nature. Most of the gases are found everywhere in the nature and so they are used widely in electrical engineering primarily for insulating purposes.

When the applied voltage is low, a small current flows between the electrodes via gaseous medium separating these electrodes, and the gas retains all the insulating properties. But when the voltage applied is large enough, a sharp increase in currents between the electrodes through the gaseous medium is observed leading to electrical breakdown of the gaseous medium.

A strongly conducting spark formed during breakdown produces a short circuit between the electrodes with heavy currents. The maximum voltage applied to the insulation (gas) at the moment of breakdown caled breakdown voltage.

A gas in its normal state is almost a perfect insulator, however, when a high voltage is applied between two electrodes immersed in a gaseous medium the gas becomes a conductor and an electrical breakdown occurs. The process primarily responsible for the breakdown of gas are ionization by collison, photo-ionization and secondary emission processes.

## Arc discharge in electric breakdown

Arc discharge is an electric discharge characterized by the production of light, high cathode-current densities and a low voltage drop at the cathode.

It is one of the types of stationary electric discharge in gases. The formation of an arc discharge is proceded by a short transient process in the space between the electrodes (the discharge gap). The duration of the transient process (stabilization time of the discharge) is usually about $10^{-6}$ to $10^{-4}$ sec, depending on the pressure and the type of gas, the width of the discharge gap and the condition of the electrode surfaces.

The arc discharge is produced by ionizing the gas in the gap. In other cases, it is produced by heating one ~~of~~ or both electrodes to a high temperatu[re] or by moving them apart after they have been touching for a short time.

An arc discharge may also be developed as a result of an electric breakdown of the discharge gap during a brief, sharp increase of the voltage between the electrodes.

If the breakdown occurs when the gas pressure is close to atmospheric pressure, then the transient proce[ss] that precedes the arc discharge is caued spark discharge.

Arc discharge is widely used to smelt matals in arc furnaces, in gas-discharge light sources, for electri[c] welding and a plasma source in plasmatrons.

## (*) Electrical Conduction in Gases:-

In gases medium, a few electrons produced by ultra violet rays falling on the cathode, ionize neutral gas particles producing positive ions and additional electrons. These additional electrons make ionizing collisions and thus the process repeats itself. The number of electrons reaching the anode is greater than those liberated at the cathode. The positive ions also reach the cathode and give rise to secondary electrons.

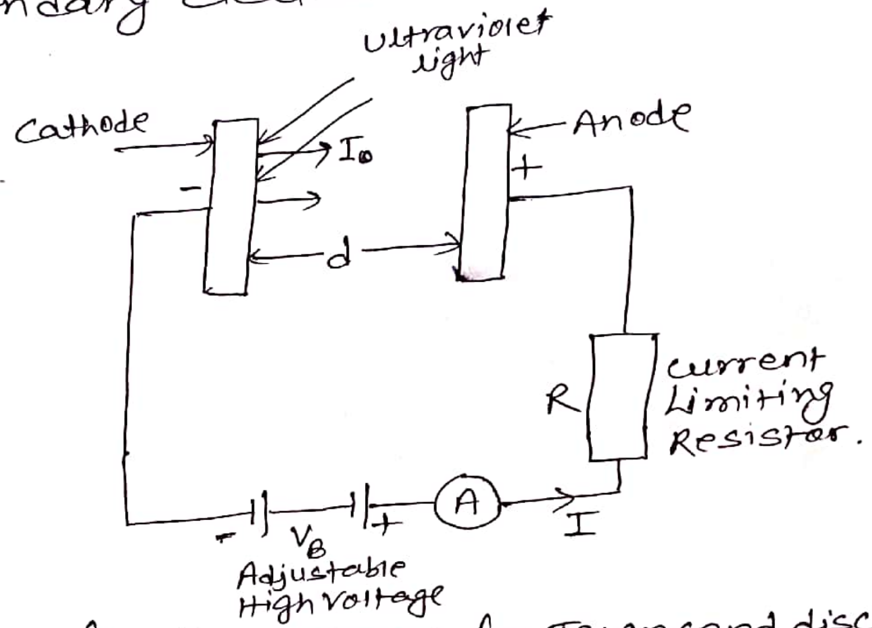


fig:- Arrangement for Townsend discharge.

In the above figure, let $n_0$ be the number of electrons emitted from cathode & $\alpha$ (called Townsend's first ionization coefficient) be the average ionizing collisions made by electron per centimeter travel in the direction of the field, $n_x$ be the number of electrons at a distance $x$ from the cathode, then,

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

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

& $n_x = n_0 \exp(\alpha x)$.

$\therefore n_d = n_0 \exp(\alpha d)$ $\because$ Here, $x = d$.

& $\boxed{I = I_0 \exp(\alpha d)}$, where $I_0$ is the initial current. //