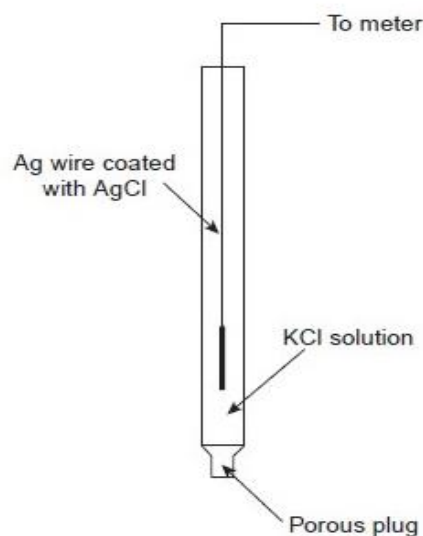


## ELECTROCHEMISTRY AND ITS APPLICATIONS

### ELECTRODES:

#### Silver-Silver chloride (Ag/AgCl) Electrode:

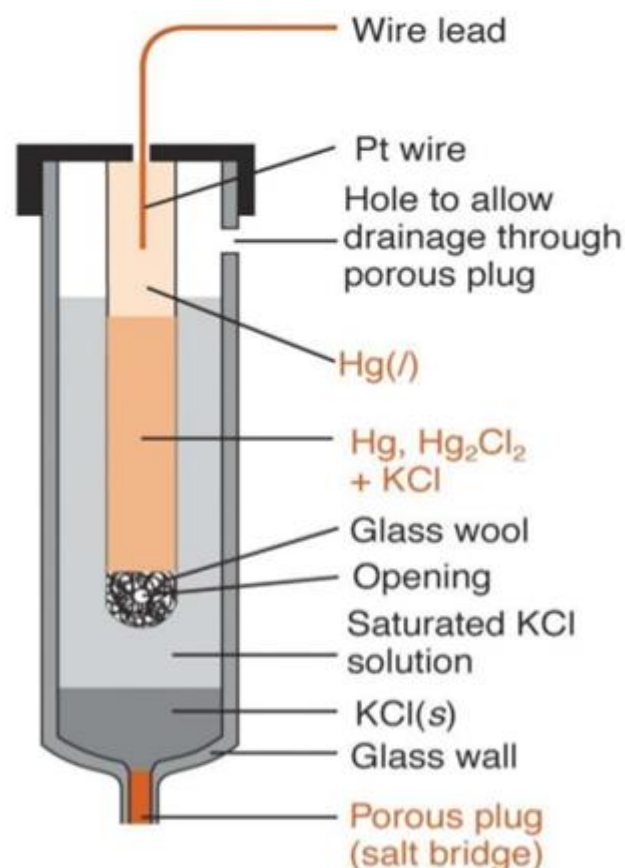
It is simply a silver wire coated electrolytically (Insert the part to be coated into 0.1 M HCl and pass 10 mA/cm<sup>2</sup> for about 1 min) with silver chloride and dipped into potassium chloride. The potential of this half-cell depends upon temperature as well as concentration of potassium chloride used. Silver and silver chloride has been represented in below: Ag/AgCl/(1M KCl). To obtain the potential of any other electrode, it is combined with the silver and silver chloride electrode and the electrode potential of the resulting cell is measured. It has the advantage that it is easy to use, but it is difficult to prepare.



**Figure** Schematic diagram of a Ag/AgCl electrode.

**Calomel electrode:** it consists of an inner jacket and outer sleeve shown in figure. The inner tube (jacket) consists platinum wire contact with mercury and plugged with mixture of calomel (Hg<sub>2</sub>Cl<sub>2</sub>) and Potassium chloride (KCl). This is surrounded by an outer sleeve and the tip is filled with potassium chloride crystals and porous plug of asbestos. The space between the inner jacket and outer sleeve filled with either saturated potassium chloride (KCl), 1.0N KCl and 0.1 N KCl, it is respectively called as Saturated Calomel Electrode (SCE), Normal Calomel Electrode (NCE) and Decinormal Calomel Electrode (DNCE). The potential of the electrode depends upon the concentration of potassium chloride and temperature.

Calomel electrode when filled with	Potential in (mV)	
	At 20°C	At 25°C
Saturated KCl	250	246
1N KCl	286	285
0.1 N KCl	338	338



**Figure: Saturated Calomel electrode**

To obtain the potential of any other electrode, it is combined with the saturated calomel electrode and the electrode potential of the resulting cell is measured.

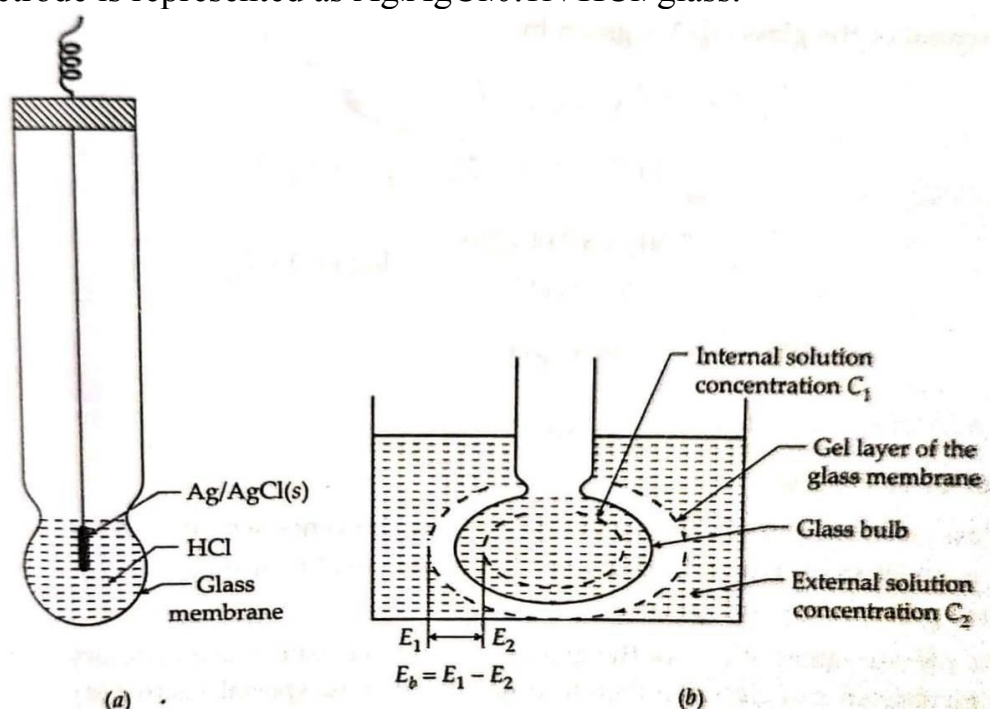
**Advantages of calomel electrode:**

- It is easy to construction
- Potential measurements' are reproducible and stable
- It does not affect with temperature.

**Glass Electrode:**

**Construction:** The glass electrode is made of special glass of relatively low melting point and high electrical conductivity. It is containing  $\text{Na}_2\text{O}$  (22%),  $\text{CaO}$  (6%) and  $\text{SiO}_2$  (72%). The glass electrode is shown figure. It consists of thin glass bulb filled with 0.1 N HCl (hydrochloride solution) and Silver wire coated with Silver chloride is immersed in it. Here Ag/AgCl electrode acts as an internal reference electrode.

The glass electrode is represented as  $\text{Ag}|\text{AgCl}||0.1\text{N HCl}||\text{glass}$ .



**Figure: Glass electrode**

**Principle:** when the glass electrode is immersed in another solution, whose pH value is to be determined, there develops a potential between the two surfaces of the membrane. The potential difference is developed; it is proportional to the difference in pH value. The glass membrane of the glass electrode undergoes an ion exchange reaction, the  $\text{Na}^+$  ions on the glass are exchanged for  $\text{H}^+$  ions.

If more number of  $\text{H}^+$  ions is exchanges with  $\text{Na}^+$  ions, the solution is acidic. Hence its  $\text{pH} < 7$ . If less number of  $\text{H}^+$  ions are exchanges with  $\text{Na}^+$  ions, the solution become basic. Hence its  $\text{pH} > 7$ .

The potential of the glass electrode is given by

$$E_B = E_1 - E_2 = \frac{Rt}{nF} \ln \frac{C_2}{C_1}$$

$$E = E^0 - 0.059 (\text{pH}_1 - \text{pH}_2)$$

$$E = E^{\circ} + 0.059 \text{ pH1} - 0.059 \text{ pH2}$$

Where:  $E^{\circ}$ : Standard electrode potential, pH1: pH of solution inside the bulb, pH2: pH of test solution (outside). Since pH1 is constant  $E^{\circ} + 0.059 \text{ pH1}$  is also another constant.

$$E = E^{\circ} - 0.059 \text{ pH2}$$

#### Advantages of glass electrode:

- Glass electrode is most convenient and simple to use
- It is not easily poisoned
- Equilibrium is rapidly achieved
- The results are accurate
- It could be used turbid, colour and colloidal solutions
- pH measurement is possible even with few milli literes of solution
- it could be used both alkaline and oxidizing solutions

#### Disadvantages:

- it is extremely fragile, since it contains a very thin bulb
- minute abrasions on the surface of the tip, damages the electrode
- it cannot be used with simple potentiometers, because of high resistance.

**Nernst equation:** Nernst equation explains the effect of electrolytic concentration on electrode potential.

Let us consider general electrode chemical reaction:



For the above electrode reaction free energy ( $\Delta G$ ) can be calculated provided standard free energy ( $\Delta G^{\circ}$ ), Gas constant (R), Temperature (T), activity of product ( $a_{product}$ ) and activity of reactant ( $a_{reactant}$ ) are known, using the following equation

$$\Delta G = \Delta G^{\circ} + RT \ln \left[ \frac{a_{product}}{a_{reactant}} \right]$$

Since:  $\Delta G = -nFE$  and  $\Delta G^{\circ} = -nFE^{\circ}$

Hence:

$$E = E^{\circ} - \frac{2.303 RT}{nF} \log \left[ \frac{a_{product}}{a_{reactant}} \right]$$

This is **Nernst equation**

where E is electrode potential,  $E^{\circ}$  is standard electrode potential, F is faraday of electricity, T is temperature, R is gas constant and a is activity.

At=298K,

Putting the value of  $R = 8.314 \text{ JK}^{-1} \text{ mol}^{-1}$ , and  $F = 96500 \text{ C}$  we get

$$E = E^{\circ} - \frac{0.0591}{n} \log \left[ \frac{a_{product}}{a_{reactant}} \right]$$

In dilute solutions, activity may be replaced by molar concentration terms

$$E = E^{\circ} - \frac{0.0591}{n} \log \left[ \frac{[M_{(s)}]}{[M^{n+}(aq)]} \right]$$

For pure solid,  $[M(s)] = 1$

$$E = E^{\circ} - \frac{0.0591}{n} \log \left[ \frac{1}{[M^{n+}(aq)]} \right]$$

The above equation is **Nernst equation** for the electrode at 298K

And at any other temperature (T),

$$E = E^{\circ} - \frac{2.303RT}{nF} \log \left[ \frac{1}{[M^{n+}(aq)]} \right]$$

### Nernst equation for a cell

Nernst equation can also be applied to any cell reaction such as

$$aA + bB \rightleftharpoons cC + dD$$

$$E = E^{\circ} - \frac{2.303RT}{nF} \log \left[ \frac{[C]^c [D]^d}{[A]^a [B]^b} \right]$$

Thus, **Nernst equation** is applicable for the determination of electro motive force (emf) of the cell.

**Potentiometry (potentiometric titrations):** Potentiometric titrations are those titrations which involves the measurement of electrode potentials with the addition of titrant for the determination of equivalence or end point so that substances can be estimated quantitatively.

These are powerful and comfortable analytical methods for a wide range of advantages

### Advantages:

- it could be used for coloured solutions, dilute solutions or turbid suspensions
- actual potential of reference electrode need not be known since it is maintained as constant through the titration
- titration can be automated
- mixtures of components can be titrated
- inexpensive method with more accuracy

**Theory:** For any redox reaction

$$aA + bB \rightleftharpoons cC + dD$$

$$E = E^{\circ} - \frac{2.303RT}{nF} \log \left[ \frac{[C]^c [D]^d}{[A]^a [B]^b} \right]$$

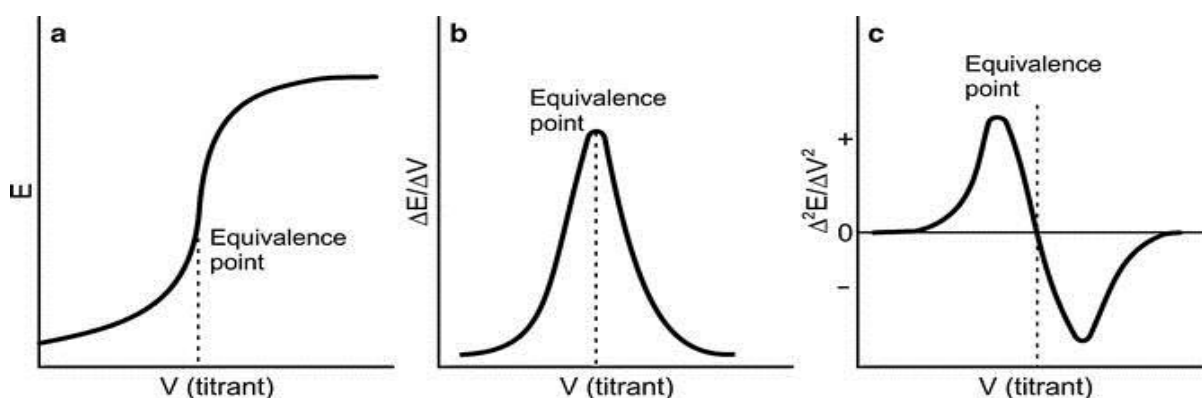
Where  $E^{\circ}$  is the standard electrode potential of the cell. The potential of the system is thus controlled by the ratio of the concentration of the oxidized to the reduced species present. As the reaction proceeds the ratio and hence the potential changes more rapidly in the vicinity of the end point of the titration. This is thus followed potentiometrically.

**Procedure:** the titration can be done manually or under automation. When it is done manually, a beaker with a stirrer and a pipette are sufficient. In case of automated models, a

sample cell which can hold a pair of electrode. The pair of reference and indicator electrode depends on the type of titration. For example: acid-base titration and redox titration etc. the most titrations saturated calomel electrode is used as reference electrode. Only indicator electrode varies with respect to the type of titrant.

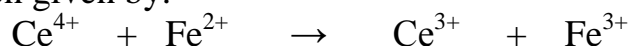
**Determination of endpoint:** any one of the following three methods could be used for the determination of end point in potentiometry. It is done graphically by using

- A normal titration curve: the graph between potential (E) vs volume of titrant (V) or pH vs volume of titrant
- First derivative curve: the graph between direct potential with respect to volume ( $\Delta E/\Delta V$ ) is plotted against to volume of titrant (V). the maximum of the curve gives the end-point.
- Second derivative curve: the graph between the potential with respect to volume ( $d^2E/dV^2$ ) is plotted against the volume of titrant (V). the point at which the second derivatives crosses zero is the inflection point and is takes is the end point.



### Redox titration:

The general redox reaction given by:



$\text{Ce}^{4+}$  is an oxidizing agent which oxidises  $\text{Fe}^{2+}$  (ferrous) to  $\text{Fe}^{3+}$  (Ferric ion). In this process  $\text{Ce}^{4+}$  (ceric) gets reduced to  $\text{Ce}^{3+}$  (cerous) ions.

$$E = E^\circ - \frac{0.059}{n} \log \left[ \frac{\text{Oxidation}}{\text{Reduction}} \right]$$

Let us apply for the electrode chemical reaction

$$E = E^\circ - \frac{0.059}{n} \log \left[ \frac{\text{Fe}^{3+}}{\text{Ce}^{3+}} \right]$$

Where:  $E^\circ$ : Standard potential, n: no of electrons involved in the reaction.

**Reference electrode:** saturated calomel electrode or silver-silver chloride electrode

**Indicator electrode:** Platinum wire.

### APPLICATIONS OF POTENTIOMETER:

- Used in the determination of the % of acetyl salicylic acid in aspirin tablets.
- Used in the determination of the % acetic acid in the vinegar.
- Used in the determination of the carbonate.

4. Used in the acid base titrations.
5. Used in the precipitation titrations.
6. Used in the complexometric titrations.
7. Used in the biamperometry.
8. Used for the estimation of the saccharin in the food components.

### Conductometric titration:

**Principle:** Conductometric titration is a one type of volumetric analysis, to determine end-point of titration by measuring conductivity between analyte and titrant is known as **conductometric titration**. During the course of titration, the conductivity of the solution changes, since there is a **change of number of ions** and the **mobility of ions**. At the end point of the titration, there is a sharp change in the conductivity of a solution shown by the intersection of the lines in the graph of conductivity Vs volume of titrant added.

### Advantages:

- Prior knowledge does not required strength of acid and base in any volumetric titration.
- Indicators not required to detection of end point
- End point determination is very easy in conductometric titration. Hence there is no keen observation is not required for end point detection.
- It could be used in very dilute solutions, mixture of acid and bases,

**Procedure:** In a conductometric titration, titration vessel (beaker), a stirrer for mixing, automatic or manual burette to deliver the titrant is sufficient. A conductivity meter with conductivity cell is used to make conductivity measurements. The conductivity is measured in millimhos or micromhos. The titrant is added in small increments like 0.5ml or 1.0 ml. the solution is mixed properly and measure the conductivity. Several conductivity measurements are noted few before and after the approximate end-point.

A graph of conductivity vs volume of titrant is drawn and the point of intersection of lines are known as end point or equivalent point. This corresponds the volume of tirant is required to neutralize the reactants or analyte or sample present in the given solution.

$$\text{Actual conductivity} = \frac{V+v}{V} \times C$$

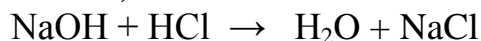
Where: V: initial volume of analyte or sample,

v: volume of titrant added and

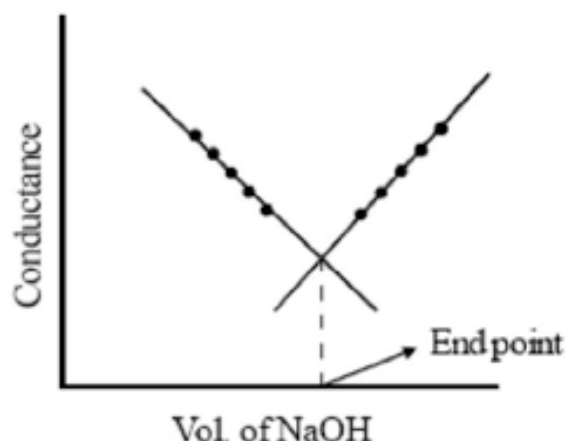
C: measured conductivity or observed conductivity.

### For example:

#### Strong acid-strong base (HCl vs NaOH):



When HCl is taken in a beaker as titrate, the initial conductivity is high, because HCl is strong acid it is completely dissociate into  $\text{H}^+$  ions and the ionic of  $\text{H}^+$  ions is high initially. When NaOH is added as titrant, the  $\text{OH}^-$  and  $\text{H}^+$  ions reacts to produce water and the number of  $\text{H}^+$  ions decreases the conductivity also decreases after every addition. The titration has been continuing with NaOH. At certain point the conductivity gradually increases due to increasing number of  $\text{OH}^-$  ions.



A plot of conductivity vs volume of titrant (i.e volume of NaOH) shows V-shaped curve as shown in figure. The first part of the curve shows steep fall in conductivity because of decreasing in  $H^+$  ions and second part of the curve shows gradually increases because of the increasing in  $OH^-$  ions.

#### Applications of conductometry:

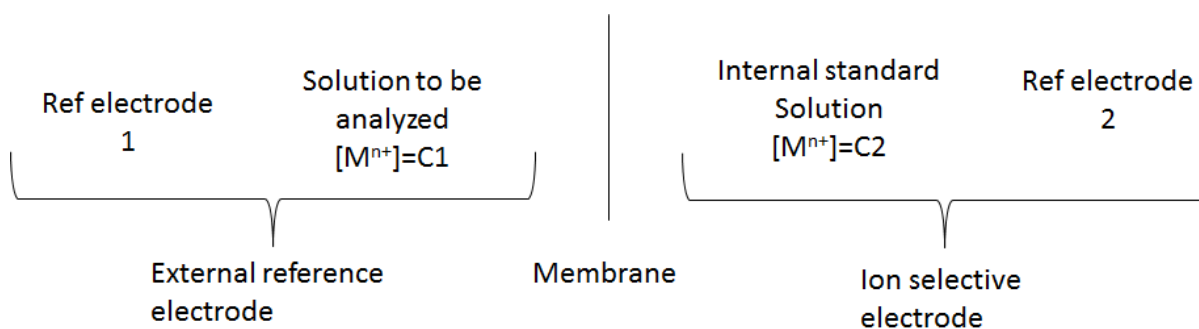
1. It is used for determine the end point of acid-base titrations
  - a. strong acid vs strong base ex:  $HCl$  vs  $NaOH$
  - b. Strong acid vs weak base ex:  $HCl$  vs  $NH_4OH$
  - c. Weak acid vs weak base ex:  $CH_3COOH$  vs  $NH_4OH$
  - d. Weak acid vs Strong base ex:  $CH_3COOH$  vs  $NaOH$
  - e. Mixture of acids vs base ex:  $HCl$  and  $CH_3COOH$  vs  $NH_4OH$
2. Conductometry is used to determine the acids 'basicity'. The basicity is defined as the number of carboxylic acid groups attached to the molecules.
3. Use in the determination of the sparingly soluble salts such as barium sulfate and lead sulfate.
4. It is use in the determination of the purity of water.
5. The determination of the salinity of the sea water.
6. It is use in the determination of the ionic product of the water.
7. Also use in the quantitative analysis of the compound.
8. It is used to measure the river and lake water pollution
9. Determination of atmospheric sulphur dioxide
10. To check the solubility of sparingly soluble salts.

#### Electrochemical sensors:

**Potentiometric sensors:** Ion Selective Electrode (ISE) is most true representative potentiometric sensor which is shown in figure. Ion Selective Electrode is electrode (or) electrode assembly with a potential that is dependent on the concentration of the ionic species in the test solution and is used for electro analysis. Most common Ion Selective Electrodes are often membrane type of electrodes. The Ion Selective Electrodes have the ability to respond to certain specific ions and develop a potential. The potential developed is a measure of the concentration of the species of interest. These electrodes use a membrane which is sensitive to a particular chemical species.

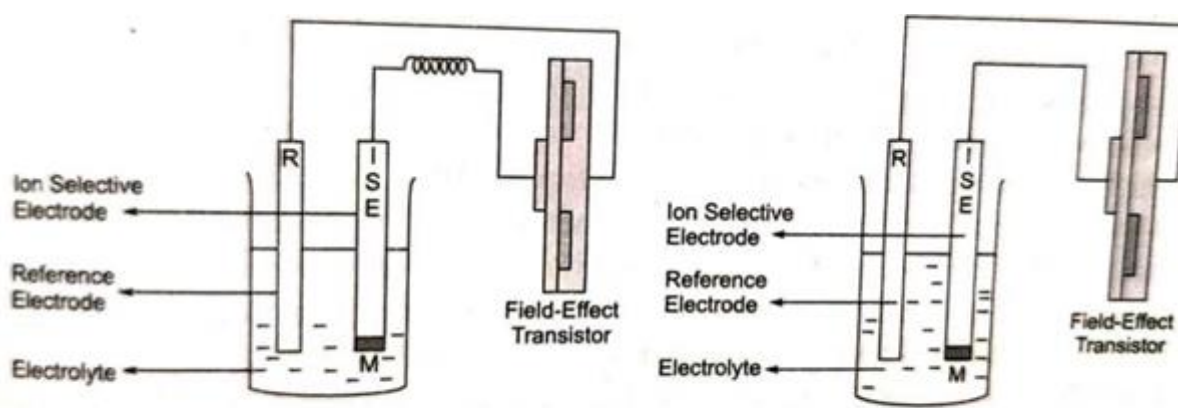
Measurement of concentration of  $Mn^{+}$  ion in solution using ion selective membrane electrodes.

The schematic cell for this purpose can be given as:



The membrane potential is given by the equation

$$E_{M^{n+}} = E^0 + \frac{RT}{nF} \ln \frac{C_2}{C_1}$$



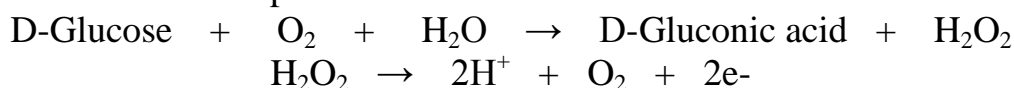
**Fig.** Potentiometric Sensors. (a) Ion-selective electrode (ISE) with reference electrode wired to the field-effect transistor amplifier. (b) The electrical connection between Ion Selective Electrode and the amplifier in shorter.

### Example: Estimation of glucose with potentiometric sensor:

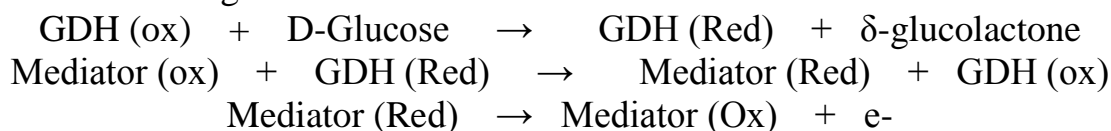
Glucose is an electrically neutral molecule. Hence electrically neutral (or) non electrolyte molecule does not give any response (or) signal.

The neutral glucose molecule has to be converted into ions. Enzymatic oxidation of glucose to gluconic acid. The subsequent measurement of the liberated hydrogen ions.

The electrochemical reactions proceed as follows.



When glucose dehydrogenase (GDH) was applied to electrochemical reactions using electron transfer mediator in the glucose sensors as follows



### Amperometric sensors:

**Principle:** the principle of Amperometry is basis of the measurement of the current between the working and counter electrode which is induced by a redox reaction at the working electrode. The signal or response is with respect to the diffusion current that is in Amperometric sensors. During the titration the concentration of electroreducible ion changes



and hence the diffusion current also changes. At the end point there is a sharp change in the diffusion current as shown by the curve of diffusion current vs volume of titrant. The principle of potentiometric titrations can be well explained from the following curve:

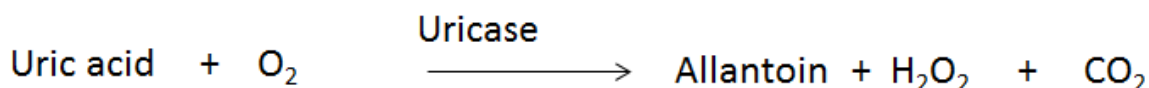
The current-voltage curve of different concentrations of the same electroreducible ions shows that, at low concentration, there is less diffusion current and at high concentration there is more diffusion current. During the titration, as the concentration of the electroreducible ions changes the diffusion current also changes.

The redox process at the electrode represent charge transfer reactions that can proceed in either direction (oxidation or reduction) each with its own velocity. Some electrochemical reactions proceed very fast in both directions and their charge transfer resistance is very low, hence the chemical reactions are known as reversible reactions. On the other hand some electrochemical reactions are slow and charge transfer resistance is very, hence the electrochemical reactions are known as irreversible reactions.

**For example: Estimation of Uric acid (UA):** estimation of uric acid (UA) a major nitrogenous compound in urine, is the product of purine metabolism in the human body and is related to many clinical disorders. Here one of the major problem estimation of uric acid is difficult due to ascorbic acid interference, which exhibit similar oxidation potential.

There are two methods for the measurement of uric acid by enzymatic and non-enzymatic methods.

The enzymatic procedures using uricase have been developed based on Amperometric detection of  $\text{H}_2\text{O}_2$  produced in the reaction below.



Other enzymatic procedures are based on electron transfer mediators, the reactions are as follows:



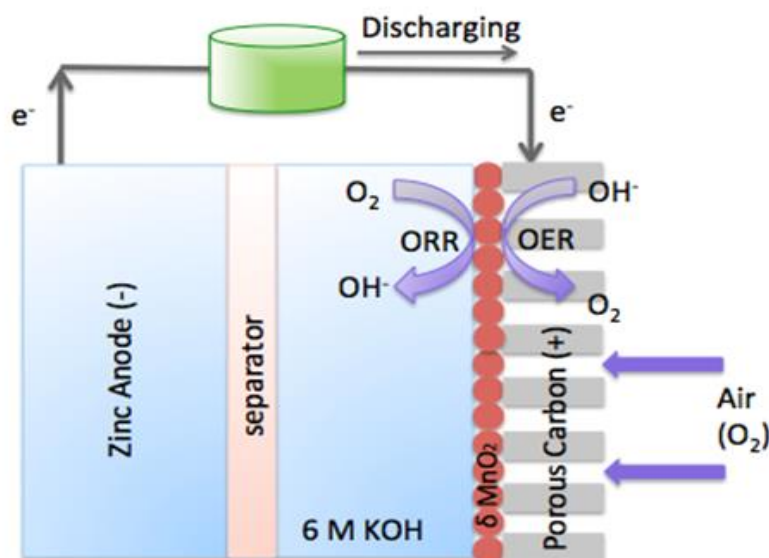
## BATTERIES

**Primary battery:** it is defined as primary battery can convert chemical energy convert into electrical energy, it could be used once only, it could not be used again and again further. Primary battery cannot be recharged.

Ex: Zinc-Air, Dry or Laclanche cell, Zinc and  $\text{MnO}_2$ , voltaic cell and Daniel cell etc...

### Zinc-Air Battery:

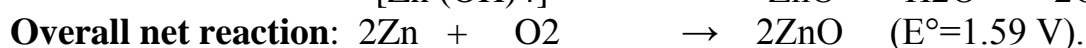
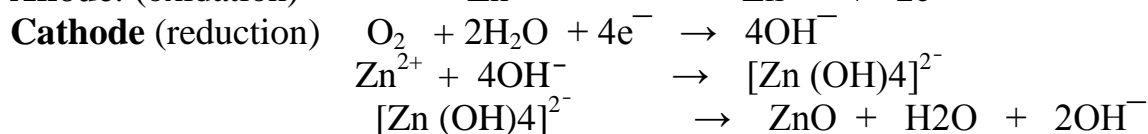
**Construction:** it is one type of primary battery. It is composed of pure zinc porous metal acts anode and the atmospheric oxygen content from air acts as cathode. The cathode is made of carbon porous material which converts into hydroxyl ion. The zinc anode involves oxidation and atmospheric oxygen involves as reduction at cathode which shown in the figure.



**Figure: Zinc-Air battery:** oxygen reduction reaction (ORR) and oxygen evolution reaction (OER)

**Discharging:** During discharging the battery zinc porous anode which is saturated with an electrolyte to form zinc hydroxyl precipitate at anodic electrode. At cathode atmospheric oxygen reacts with carbon porous it converts into hydroxyl ion.

**Mechanism:** the electrochemical reaction in Zinc-Air battery



**Advantages:**

- It is inexpensive materials
- High energy density
- It exhibit low power
- Zinc air battery could store more amount of energy
- Excellent shelf life when it is sealed (discharging rate 2% per year)
- These cells are available in range of button and coin cell sizes.

**Disadvantages:**

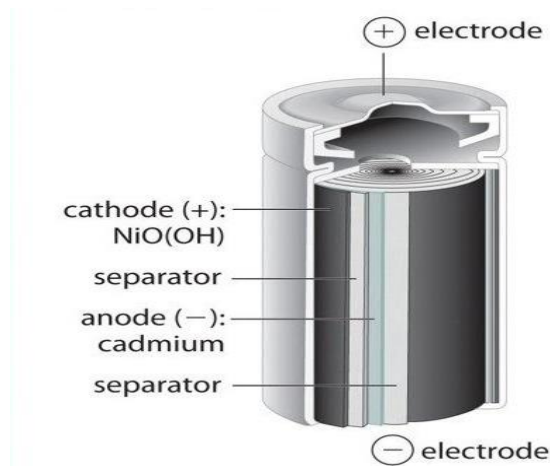
- Carbon dioxide from air develops carbonate which reduces the conductivity
- It is more sensitive for humid and extreme temperature
- High self-discharge

**Applications:**

- It is used mainly in watches and hearing aids
- Large size batteries are used in telecoms, railway remote signaling, safety lamps at road, rail construction sites and power sources for electric fences.
- It is used in film cameras.

**Secondary battery:** it is defined as chemical energy is converted into electrical energy and by applying electrical energy is converted into chemical energy. Hence these type of cells could be used again and again. These batteries could be charged again and again. Ex: Lithium ion battery, Ni-Cd battery, Lead-Acid battery etc.

**Nickel – Cadmium battery:** Nickel-Cadmium cell is secondary type and recharge cell.



**Figure:** Nickel-Cadmium battery

**Construction:** Nickel-Cadmium cell consists of Cadmium anode and a metal grid containing a paste of  $\text{NiO}_2$  acting as a cathode. Anode and cathode are separated with potassium hydroxide (KOH) solution.

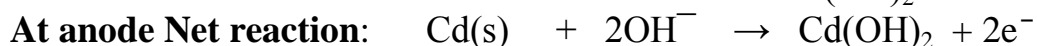
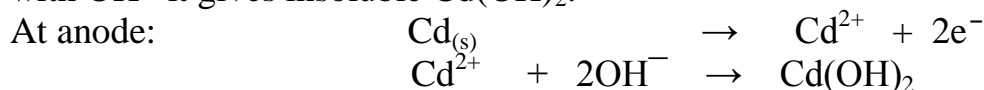
The Nickel-Cadmium cell is represented as below



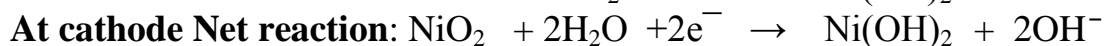
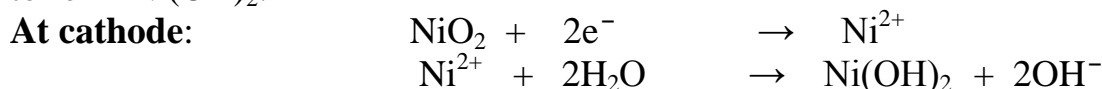
**Working:**

**Discharging:**

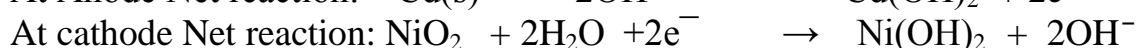
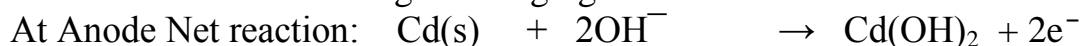
**At anode:** When Nickel-Cadmium battery operates, at the anode cadmium is undergoes oxidation takes place, hence Cd is converted  $\text{Cd}^{2+}$  by losing two electrons. The  $\text{Cd}^{2+}$  reacts with  $\text{OH}^-$  it gives insoluble  $\text{Cd}(\text{OH})_2$ .



**At cathode:** at cathode  $\text{NiO}_2$  is reduced to  $\text{Ni}^{2+}$  ions which further combine with  $\text{OH}^-$  ions to form  $\text{Ni}(\text{OH})_2$ .



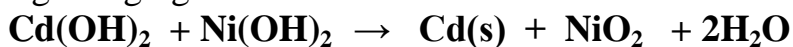
Overall net reaction during discharging at anode and cathode electrochemical reaction.



From the above cell reactions, it is clear that there is no formation of gaseous products, the products  $\text{Cd}(\text{OH})_2$  and  $\text{Ni}(\text{OH})_2$  precipitate on the anode and cathode electrode surfaces respectively.

**Recharging the battery:** the recharging process is reverse to the discharging battery. When current is passed thorough in opposite direction, the electrode reaction gets reversed. As a result Cadmium (Cd) gets deposited on anode and  $\text{NiO}_2$  is deposited on cathode electrodes.

The net reaction during charging:



**Advantages:**

- it is smaller and lighter
- it has longer in life than lead storage cell
- like a dry cell it could be packed in a sealed container.

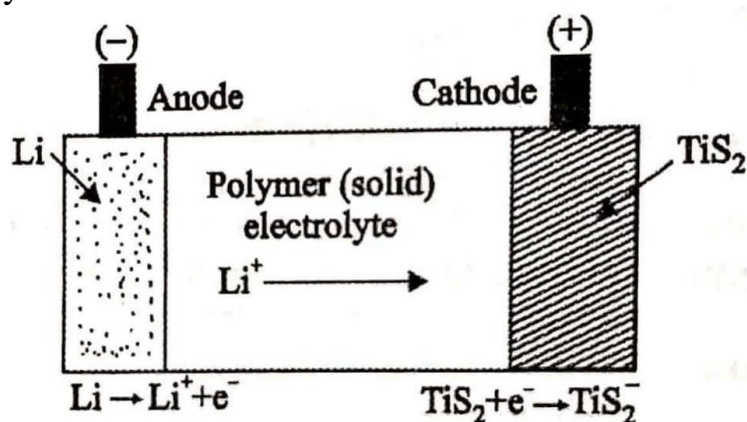
**Disadvantages:** it is commercially more expensive than lead storage cell.

**Applications:**

- it is used in radios, personal pagers and radio control
- it is used in calculators, watches
- it is used in portable computers
- it is used in tape recorders, cassette players and recorders
- it is used in portable hand tools and its applications
- it is used in digital cameras, photoflash equipment's and electronic flash units.

**Lithium ion battery:**

Lithium ion battery is a solid state battery because instead of liquid or paste electrolyte, solid electrolyte is used.



**Figure: Lithium ion battery**

**Construction:** The lithium battery consists of lithium metal acts as anode and a Titanium sulphide ( $\text{TiS}_2$ ) acts as cathode. The anode and cathode are separated with solid polymer electrolyte (polypropylene carbonate, Dimethoxy ethane etc...). The solid polymer electrolyte which allows only transfer of ions but not that of electrons.

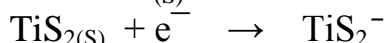
**Working principle (Discharging):** when Lithium anode is connected to  $\text{TiS}_2$  cathode through external wire, Lithium metal convert into  $\text{Li}^+$  ions due to oxidation at anode. The  $\text{Li}^+$  ions travel through solid polymer electrolyte to towards cathode ( $\text{TiS}_2$ ). The cathode material accepts the electrons and Lithium ions. Here Lithium anode is the primary source to produce  $\text{Li}^+$  ions and electron.

The electrochemical reaction during discharging of the battery:

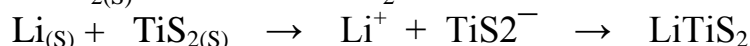
**At anode;**



**At cathode:**



**Overall reaction:**



**Recharging the battery:**

The lithium battery can be recharged by supplying an external current, which drives the lithium ions back to the anode and  $\text{TiS}_2$  is back to the cathode.

The overall electrochemical reaction during charging.

**Advantages:**

- its cell voltage is high 3.0V
- it is light in weight
- it is most negative electrode potential values, hence it produce high voltage battery
- battery consists of solids hence there is no risk of leakage from the battery
- it could be made variety of sizes and shapes

**Disadvantages:** it is more expensive when compared with other batteries

**Applications:** lithium ion batteries are used in calculators, watches, cameras, mobile phones, laptop computers etc.

**FUEL CELLS**

**Fuel Cells:** it is defined; fuel cell is voltaic cell, which converts the chemical energy of the fuels directly into electricity without combustion. It converts the energy of the fuel directly into electricity. In these cells reactants, products and electrolysis pass through the cell.

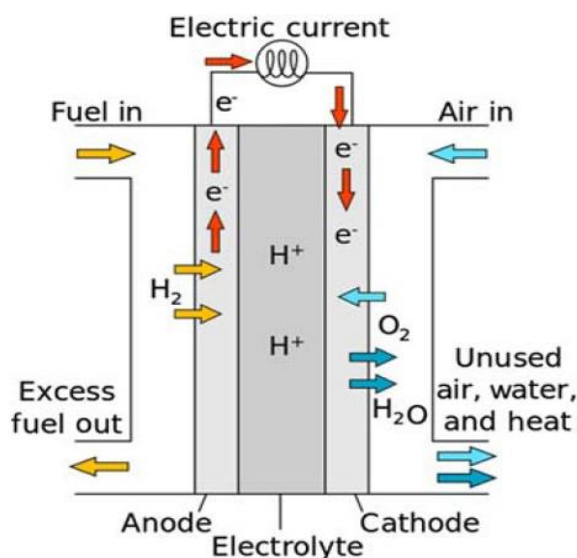


Ex:  $\text{H}_2\text{-O}_2$  fuel cell and Methanol and  $\text{O}_2$  fuel cell

**Hydrogen-Oxygen ( $\text{H}_2\text{-O}_2$ ) fuel cell:**

Hydrogen-Oxygen fuel cell is the simplest and most successful fuel cell, in which the hydrogen fuel cell and the oxidiser-oxygen and the liquid electrolyte are continuously passed through the cell.

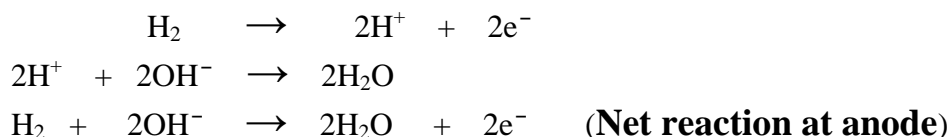
**Construction:** it consists of two porous electrodes anode and cathode. These porous electrodes are made of compressed carbon containing a small amount of catalyst (Pt, Pd, Ag). In between the two electrodes an electrolytic solution such as 25% KOH or NaOH is filled. The two electrodes are connected through volt meter.



**Figure:  $\text{H}_2\text{-O}_2$  fuel cell**

**Working:** Hydrogen (the fuel) is passed through the anode compartment, where it is oxidised. The oxygen (oxidiser) is passed through the cathode compartment. Where it is reduced.

**At anode:** hydrogen gas passed through the anode is oxidised with the liberation of electrons which then combine with hydroxide ions to form water.

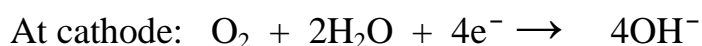


**Multiply by 2:**  $2\text{H}_2 + 4\text{OH}^- \rightarrow 4\text{H}_2\text{O} + 4\text{e}^-$

**At cathode:** the electrons, produced at the anode, pass thorough the external wire to the cathode where it is absorbed by oxygen and water to produce hydroxide ions.



**Overall electrochemical reactions:**

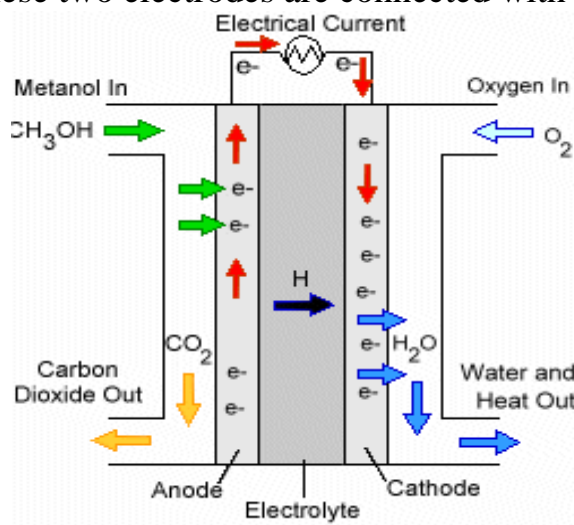


**Applications:**

- it is used in space vehicles, submarines and military vehicles
- Water which is obtained from  $\text{H}_2\text{-O}_2$  fuel cell, used by astronauts.

**Methanol and  $\text{O}_2$  fuel cell;**

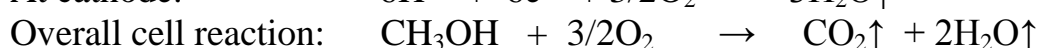
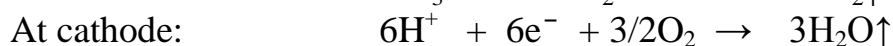
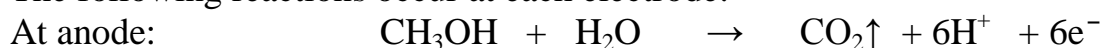
Methanol oxygen fuel cell is made of two fuel electrodes. One consists of porous nickel plate coated with a catalyst platinum black and the other is similar porous nickel plate coated with a silver catalyst. In between these electrodes 25% NaOH or KOH are used as electrolytic solution. Here silver coated nickel porous electrode allowed the air and it acts as cathode and methanol vapour are transferred through platinum coated nickel porous electrode acts as anode. These two electrodes are connected with volta-meter.



**Figure: Methanol-Oxygen fuel cell**

When the cell operates the water vapour and the carbon oxide are liberated at around the electrodes.

The following reactions occur at each electrode:



**Applications:** it is used in simple transistorised radio.