

## MODULE 1

### ELECTRODE AND ENERGY CONVERSION SYSTEMS

**Electrode System:** Introduction, types of electrodes. Reference electrode - Introduction, calomel electrode –construction, working and applications of calomel electrode. Electrolyte Concentration cell– Definition, construction, working and Numerical problems. Ion selective electrode – definition, construction and applications of glass electrode. Determination of pH using glass electrode.

**Energy conversion Systems:** Introduction to batteries, construction, working and applications of Lithium ion. Construction, working and applications of photovoltaic cells. Quantum Dot Sensitized Solar Cells (QDSSC's)- Principle, Properties and Applications.

**Self-learning:** Working of glass electrode, Silver-Silver chloride electrode Sodium ion batteries.

#### Electrode:

An electrode is a metal whose surface serves as the location where oxidation-reduction equilibrium is established between the metal and the solution. The electrode can either be an anode or a cathode.

Ex: Copper electrode, Zn electrode, Ni electrode etc.

**Single electrode potential [E]:** Single electrode potential is the potential developed at the interface between the metal and the solution, when the metal is in contact with a solution of its own ions. (OR) It is the tendency of the metal to lose or to gain electrons when it is in contact with a solution of its own ions.

**Standard electrode potential [E°]:** The standard electrode potential is defined as the potential developed when the electrode is in contact with a solution of unit concentration and pressure at 298K.

**Emf of the cell:** The potential difference between the two electrodes of a galvanic cell which causes the flow of current from one electrode (higher potential) to the other (lower potential) is called the electromotive force of the cell or the cell potential.

#### Calculation of standard emf of a cell:

The standard emf of the cell is calculated using the following expression

$$E^{\circ}_{\text{cell}} = E^{\circ}_{\text{cathode}} - E^{\circ}_{\text{anode}}$$

$$= E^{\circ}_R - E^{\circ}_L$$

$$E^{\circ}_{\text{cell}} = E^{\circ}_{\text{Reduction}} - E^{\circ}_{\text{oxidation}}$$

#### Types of Electrodes

**1. Metal-metal ion electrode:** This type of electrode consists of a metal in contact with a solution of its own ions.

Ex: 1. Zinc rod in a solution of zinc sulphate.

2. Copper rod in a solution of copper sulphate.

**2. Metal-metal salt ion electrode:** Here a metal is dipped in its insoluble salt that is in contact with a solution containing the anion of the salt

Ex: 1. Calomel electrode  $\text{Hg} / \text{Hg}_2\text{Cl}_2 (\text{s}) / \text{Cl}^-$

2. Silver-Silver chloride electrode  $\text{Ag} / \text{AgCl} (\text{s}) / \text{Cl}^-$

**3. Gas electrode:** Here a gas is in contact with an inert metal that is dipped in an ionic solution of the gas molecule.

Ex: SHE,  $\text{Pt} / \text{H}_2 (1\text{atm}) / \text{H}^+ (1\text{M})$

**4. Amalgam electrode:** Metal- Amalgam is in contact with a solution containing its own metal ions.

Highly active metals are used in the form of amalgams, since the activity of metal can be varied.

Ex. Zinc in mercury in contact with zinc sulphate solution  $[\text{Zn}(\text{Hg}) / \text{Zn}^{2+}]$

Ex. Lead Amalgam electrode  $(\text{Pb}(\text{Hg}) / \text{Pb}^{2+})$

**5. Oxidation-reduction electrode:** This type of electrode consists of an inert electrode (Pt or Au) immersed in a mixed solution containing both the oxidized and reduced forms of a molecule or ion.

Ex:  $\text{Pt} / \text{Fe}^{2+}, \text{Fe}^{3+}$ ,  $\text{Pt} / \text{Sn}^{2+}, \text{Sn}^{4+}$

**6. Ion-selective electrode:** It Possesses the ability to respond only to certain specific ions, thereby developing potential w.r.t that species only in a mixture and ignoring the other ions totally. In other words, the potential developed by an ion-selective electrode depends only on the concentration of species or ions of interest.

Ex: glass electrode which responds to hydrogen ions ( $\text{Ag}/\text{AgCl}/\text{HCl}/\text{Glass}$ ).

**Reference electrodes:** Reference electrodes are the electrodes whose potential is known and with reference to which, the electrode potential of other electrode can be measured.

There are 2 types of reference electrodes.

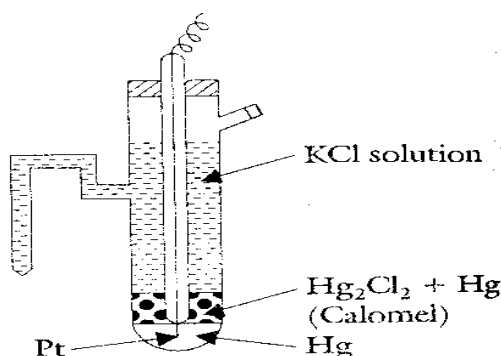
1. Primary reference electrode. 2. Secondary reference electrode

**1. Primary reference electrodes:** Standard hydrogen electrode (SHE) is the primary reference electrode and its electrode potential taken as zero at all temperature.

**2. Secondary reference electrodes:** These are the electrodes having constant electrode potential value and their potential is known with respect to SHE, hence they are called as secondary reference electrodes.

Ex: 1. calomel electrode 2. Ag-AgCl electrode.

**Calomel electrode:** The calomel electrode consists of a glass vessel containing a layer of Hg over which a paste of  $\text{Hg}_2\text{Cl}_2$  is placed. Above this there is a solution of KCl. A platinum wire is dipped into the Hg layer provides external electrical connection. A salt bridge is used to couple with other half-cell.



The half-cell is represented as  $\text{Hg} / \text{Hg}_2\text{Cl}_2 (\text{salt}) / \text{KCl} (\text{saturated})$

Calomel electrode can act either as anode or cathode depending on the other electrode used

**When it is Anode:**  $2\text{Hg} + 2\text{Cl}^- \longrightarrow \text{Hg}_2\text{Cl}_2 + 2\text{e}^-$

**When it is Cathode:**  $\text{Hg}_2\text{Cl}_2 + 2\text{e}^- \longrightarrow 2\text{Hg} + 2\text{Cl}^-$

**Net reaction is:**  $\text{Hg}_2\text{Cl}_2 (\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{Hg} + 2\text{Cl}^-$

The electrode potential may be represented by the Nernst equation as

$$E = E^\circ - 0.0591/n \log [\text{Cl}^-]^2$$

$$E = E^\circ - 0.0591/2 \log [\text{Cl}^-]^2$$

$$E = E^\circ - 0.0591 \log [\text{Cl}^-] \text{ at } 298 \text{ K}$$

**[Additional Information:** The potential of the calomel electrode depends on the concentration of KCl used. The electrode potential decreases with increase in the concentration of chloride ions.

For 0.1N KCl  $E = 0.33\text{V}$

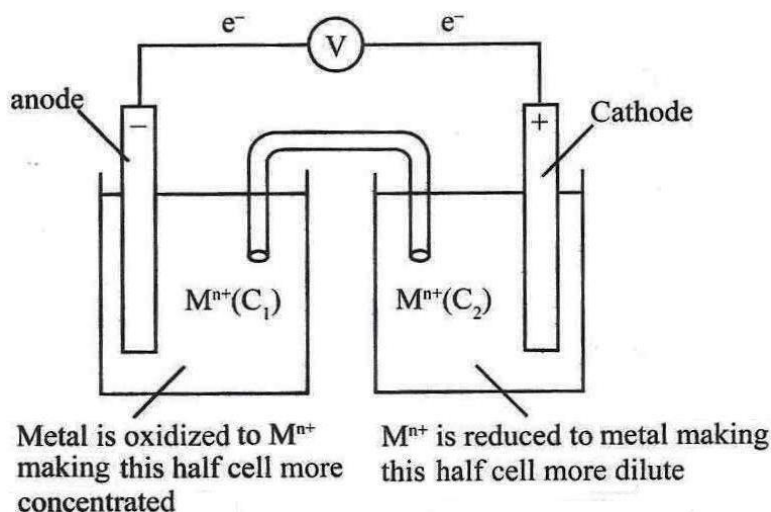
1N KCl  $E = 0.28\text{V}$

Saturated KCl  $E = 0.24\text{V}$ ]

### **Applications:**

1. Used to determine potential of metallic electrodes.
2. Most commonly used in all potentiometric measurements.

**Electrolyte concentration cells:** It is a type of galvanic cell in which electrode & electrolyte present in both the half cells are same but only the concentration of electrolyte is different.



**Cell representation:**  $\text{M} / \text{M}^{n+}(\text{C}_1) // \text{M}^{n+}(\text{C}_2) / \text{M}$

Metal immersed in the dilute solution will have lower potential act as **anode**



Metal immersed in the concentrated solution will have higher potential act as **cathode**



**Net cell reaction is:**  $\text{M}^{n+}(\text{C}_2) \longrightarrow \text{M}^{n+}(\text{C}_1)$

Nernst equation for electrolyte concentration cell is

$$E_{\text{Cell}} = E^\circ_{\text{Cell}} + \frac{0.0591}{n} \log \frac{[\text{M}^{n+}]_{\text{cathode}}}{[\text{M}^{n+}]_{\text{Anode}}}$$

$$E^{\circ}_{\text{Cell}} = E^{\circ}_{\text{cathode}} - E^{\circ}_{\text{anode}} = 0$$

$$E_{\text{Cell}} = \frac{0.0591}{n} \log \frac{[M^{n+}]_{\text{cathode}}}{[M^{n+}]_{\text{Anode}}}$$

$$E_{\text{Cell}} = \frac{0.0591}{n} \log \frac{C_2}{C_1} \text{ at } 298\text{K}$$

$E_{\text{Cell}}$  is +ve and reaction is spontaneous only when  $C_2 > C_1$

### Numerical Problems:

1. Write the electrode reactions and Calculate the EMF of the given cell at 298K,



At anode:  $\text{Ag}_{(s)} \rightarrow \text{Ag}^+ + e^-$

At Cathode:  $\text{Ag}^+ + e^- \rightarrow \text{Ag}_{(s)}$

$$\text{w.k.t} \quad E_{\text{cell}} = \frac{0.0591}{n} \log \left( \frac{C_2}{C_1} \right) \text{ at } 298\text{K}$$

$$E_{\text{cell}} = 0.0591 \log \left( \frac{1.2}{0.018} \right) (n=1)$$

$$E_{\text{cell}} = 0.1078 \text{ V.}$$

2. The EMF of the cell is 0.086V. Find the value of X at 25°C.



At Anode:  $\text{Cd}_{(s)} \rightarrow \text{Cd}^{2+} + 2e^-$

At Cathode:  $\text{Cd}^{2+} + 2e^- \rightarrow \text{Cd}_{(s)}$

$$E_{\text{cell}} = \frac{0.0591}{n} \log \left( \frac{C_2}{C_1} \right) \text{ at } 25^{\circ}\text{C}$$

$$0.086 = \frac{0.0591}{2} \log \left[ \frac{X}{0.0093} \right] \quad n=2$$

$$2.910 = \log[X] - \log[0.0093]$$

$$\log[X] = 0.8784$$

$$[X] = \text{Antilog of } 0.8784$$

$$X = 7.55\text{M}$$

3. A Concentration cell is constructed by immersing two iron electrodes in 0.01M and 0.1M  $\text{FeSO}_4$  solution. Represent the cell and calculate EMF of the cell at 28°C.

Cell representation:  $\text{Fe}_{(s)} / \text{FeSO}_4 (0.01\text{M}) // \text{FeSO}_4 (0.1\text{M}) / \text{Fe}_{(s)}$

Cell reactions: At Anode:  $\text{Fe}_{(s)} \rightarrow \text{Fe}^{2+} + 2e^-$

At Cathode:  $\text{Fe}^{2+} + 2e^- \rightarrow \text{Fe}_{(s)}$

$$E_{\text{cell}} = \frac{2.303RT}{nF} \log \left[ \frac{C_2}{C_1} \right]$$

$$= \frac{2.303 \times 8.314 \times 301}{2 \times 96500} \log \left[ \frac{0.1}{0.01} \right] = \frac{5763.289}{193000} \log[10]$$

$$E_{\text{cell}} = 0.02986\text{V}$$

4. Calculate the emf of Copper concentration cell at 25°C, where the copper ions ratio in the cell is 10.

**Given:**  $\frac{[Cu^{+2}]_{cathode}}{[Cu^{+2}]_{anode}} = \frac{C_2}{C_1} = 10$

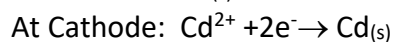
w.k.t  $E_{cell} = \frac{0.0591}{n} \log\left(\frac{C_2}{C_1}\right)$  at 298 K

$$E_{cell} = \frac{0.0591}{2} \log(10)$$

$$E_{cell} = 0.0296 \text{ V.}$$

5. A cell is obtained by combining two Cd electrodes immersed in cadmium sulphate solutions of 0.1M and 0.5M at 25°C. Give the cell representation, cell reaction and calculate EMF of the cell.

**Sol n :** Cd/CdSO<sub>4</sub>(0.1M)//CdSO<sub>4</sub>(0.5M)/Cd

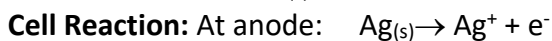
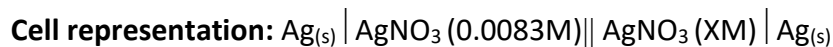


$$E_{cell} = \frac{0.0591}{n} \log\left(\frac{C_2}{C_1}\right) \text{ at } 25^\circ\text{C}$$

$$= \frac{0.0591}{2} \log\left[\frac{0.5}{0.1}\right] \quad n=2$$

$$E_{cell} = 0.0206 \text{ V}$$

6. The emf of the cell Ag/AgNO<sub>3</sub>(0.0083M)//AgNO<sub>3</sub>(xM)/Ag was found to be 0.074V at 298K. Calculate the value of x and Write cell reaction.



$$E_{cell} = \frac{0.0591}{n} \log\left(\frac{C_2}{C_1}\right) \text{ at } 298\text{K}$$

$$0.074 = \frac{0.0591}{1} \log\left[\frac{x}{0.0083}\right] \quad n=1$$

$$1.2521 = \log[X] - \log[0.0083]$$

$$1.2521 = \log[X] - (-2.080)$$

$$1.2521 - 2.080 = \log x$$

$$\log[X] = -0.8279$$

$$[X] = \text{Antilog of } -0.8279$$

$$X = 0.1486 \text{ M}$$

7. A concentration cell was constructed by immersing two silver electrodes in 0.05M and 0.1M  $\text{AgNO}_3$  solution. Write cell reaction, cell representation and calculate the Emf of the concentration cell at 298K.

**Cell representation:**  $\text{Ag}_{(s)} \mid \text{AgNO}_3 (0.05\text{M}) \parallel \text{AgNO}_3 (0.1\text{M}) \mid \text{Ag}_{(s)}$

**Cell Reaction:** At anode:  $\text{Ag}_{(s)} \rightarrow \text{Ag}^+ + \text{e}^-$

At Cathode:  $\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}_{(s)}$

$$E_{\text{cell}} = \frac{0.0591}{n} \log \left( \frac{C_2}{C_1} \right) \text{ at } 298\text{K}$$

$$E_{\text{cell}} = \frac{0.0591}{1} \log \left( \frac{0.1}{0.05} \right)$$

$$= 0.0591 \log[0.1] - \log[0.05]$$

$$= 0.0177 \text{ V}$$

8. The EMF of the cell  $\text{Cu}/\text{CuSO}_4(0.01\text{M})//\text{CuSO}_4(x\text{M})/\text{Cu}$  is 0.0295V at  $25^\circ\text{C}$ . Find the value of x.

$$E_{\text{cell}} = \frac{0.0591}{n} \log \left( \frac{C_2}{C_1} \right) \text{ at } 298\text{K}$$

$$0.0295 = \frac{0.0591}{2} \log \left[ \frac{x}{0.01} \right] \quad n=2$$

$$0.0295 = 0.0295 \log(x) - \log(0.01)$$

$$1 = \log[X] - \log[0.01]$$

$$1 = \log[X] - (-2)$$

$$1 - 2 = \log x$$

$$\log[X] = -1$$

$$[X] = \text{Antilog of } -1$$

$$X = 0.1\text{M}$$

9. An Electrolyte concentration cell consists of two Zn electrodes immersed in Zinc sulphate solutions of 0.1M and 1.0M concentration at  $28^\circ\text{C}$ . Give the cell representation, cell reaction and calculate emf of the cell.

**Cell representation:**  $\text{Zn}/\text{ZnSO}_4(0.1\text{M})//\text{ZnSO}_4(1\text{M})/\text{Zn}$

**Cell Reaction:** At anode:  $\text{Zn}_{(s)} \rightarrow \text{Zn}^{+2} + 2 \text{e}^-$

At Cathode:  $\text{Zn}^{+2} + 2\text{e}^- \rightarrow \text{Zn}_{(s)}$

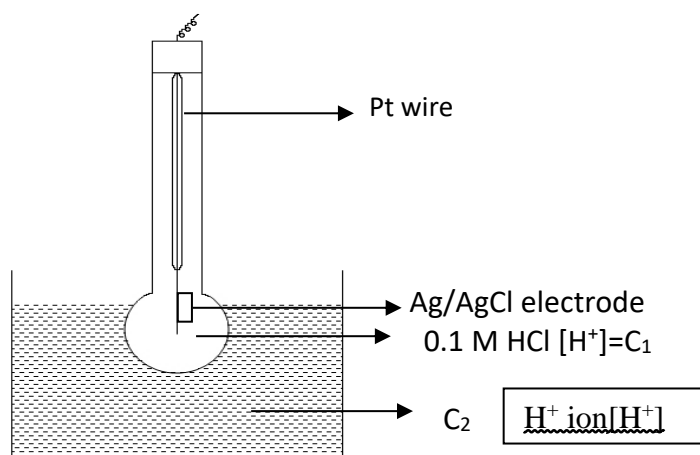
$$E_{\text{cell}} = \frac{2.303RT}{nF} \log \left[ \frac{C_2}{C_1} \right]$$

$$= \frac{2.303 \times 8.314 \times 301}{2 \times 96500} \log \left[ \frac{1}{0.1} \right]$$

$$= 0.029\text{V}$$

**Ion-selective electrodes:**

The electrode, which responds to a specific ion in a mixture by ignoring other ion, known as ion selective electrode. It consists of a thin membrane in contact with ion solution. It has the ability to respond to a specific ion and develop a potential on membrane.

**Glass Electrode:**

**Cell representation:** : Ag / AgCl / HCl (0.1M) / Glass.

**Construction:**

A long glass tube with a thin walled glass bulb (sense  $H^+$  ions up to pH-9) contains 0.1 M HCl. An Ag/AgCl electrode placed in the solution connected by a platinum wire for electrical contact. The electrode containing  $H^+$  ions of concentration  $C_1$  is dipped in another solution of concentration  $C_2$ . A change in  $H^+$  ion concentration causes a change in the composition of glass, due to exchange of ions by inner membrane and outer membrane resulting in a boundary potential  $E_b$ .

$$E_b(E_G) = L - 0.0591 \text{ pH} \quad (\text{pH} = -\log[H^+])$$

**Applications of Glass electrode:**

- Glass electrodes have been utilized in a wide range of applications including pure research.
- Measurement of sodium, lithium, or silver ions because of their high specificity for these ions.
- Control of industrial processes.
- Analysis of foods and cosmetics.
- Measurement of environmental indicators.
- Microelectrode measurements such as cell membrane electrical potential and soil acidity.

**(Extra information on Glass electrode)**

$E_b = E_1 - E_2$  ( $E_1$  &  $E_2$  is the potential developed at outer and inner membrane respectively)

Where  $E_1 = 0.0591/n \log C_2$  and  $E_2 = 0.0591/n \log C_1$

Then boundary potential

$$E_b = E_1 - E_2 = 0.0591 \log C_2 - 0.0591 \log C_1 \quad (n = [H^+] = 1)$$

$C_1$  is constant due to known electrolyte taken in bulb,

$$\text{Then } -0.0591 \log C_1 = \text{constant} = L$$

$C_2 = [H^+]$  ions in outer membrane then,

$$E_b = L + 0.0591 \log [H^+]$$

$$E_b = L - 0.0591 \text{ pH} \quad (\text{pH} = -\log[H^+])$$

### Determination of pH using Glass Electrode:

The potential of a glass electrode depends on the concentration of  $H^+$  ions. Hence, pH of a solution can be determined by using glass electrode and calomel electrode assembly. The cell assembly is represented as  $Hg/Hg_2Cl_2/Cl^- // \text{solution of unknown } P^H / \text{glass}/0.1 \text{ M HCl} / AgCl / Ag$

The emf of a cell is determined by using high impedance voltmeter.

$E_{\text{cell}}$  is the difference b/w glass electrode potential  $E_G$  and the calomel electrode potential  $E_{\text{SCE}}$

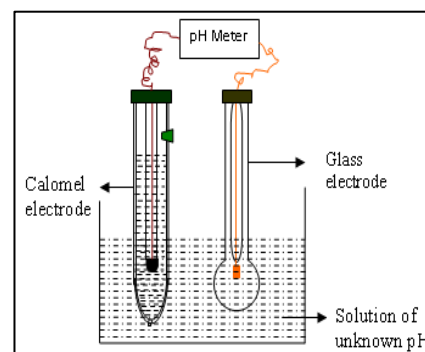
$$E_{\text{cell}} = E_{\text{cathode}} - E_{\text{anode}}$$

$$E_{\text{cell}} = E_G - E_{\text{SCE}} = L_1 - 0.0591 \text{pH} - E_{\text{SCE}}$$

$$\text{pH} = \frac{L_1 - E_{\text{SCE}} - E_{\text{cell}}}{0.0591}$$

$$(\text{Constant } K = L_1 - E_{\text{SCE}})$$

$$\text{pH} = \frac{K - E_{\text{cell}}}{0.0591}$$



In order to evaluate K, a solution of known pH is used and the potential of the cell is measured.

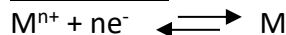
### **Extra Information**

Important class of chemical reactions is oxidation-reduction reactions.

In oxidation: a species loses one or more electrons resulting in an increase in its oxidation number.



In reduction: the species gains one or more electrons; there is a decrease in oxidation number.



A reduction process necessarily accompanies an oxidation process since electrons can be lost by a species only when there is a counterpart to receive them. Redox reaction forms the basis of electrochemical cells. An electrochemical cell consists of two electrodes which when connected by a metallic wire an electric current flow as a result of a spontaneous redox reaction.

Each electrode usually consists of a metal in contact with a solution of its own ion. Since a cell is a combination of two electrodes, each electrode is referred to as a single electrode or half-cell. A potential called the electrode potential arises at the electrode in contact with its ionic solution. The difference between the potentials of the two half-cells constitutes the electromotive force (emf) of the cell.

### Electrochemical cell:

Definition: Electrochemical cell is a device in which chemical energy is converted into electrical energy or electrical energy into chemical energy by oxidation-reduction reaction.

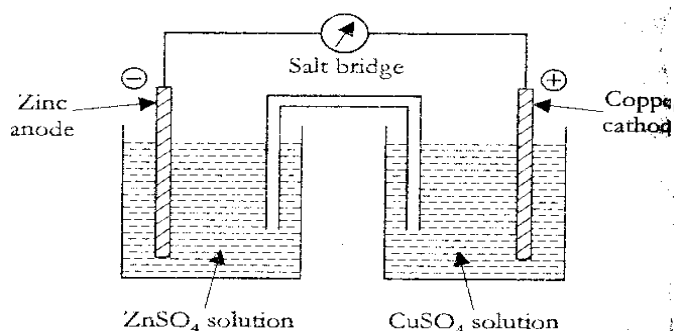
Thus, there can be two types of Electrochemical cells.

1. **Galvanic cell or voltaic cell:** the one, which converts chemical energy into electrical energy.
2. **Electrolytic cell:** the one, which converts electrical energy into chemical energy.

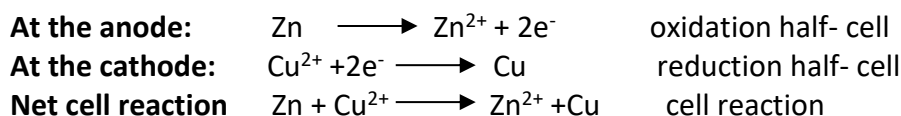


GALVANIC CELL	ELECTROLYTIC CELL
1) It is a device, in which electricity is produced by using chemical reaction.	It is a device, which converts electrical energy into chemical energy.
2) The redox reactions occurring at the electrodes are spontaneous.	The redox reactions occurring at the electrodes are non-spontaneous and are takes place only when electrical energy is supplied.
3) Each electrode is dipped in its own ionic solution and both have separate compartments.	Both the electrodes are dipped the same electrolyte solution.
4) The electrodes are of dissimilar metals.	The electrodes used may be dissimilar or of the same metal.
5) Two electrodes are connected by salt bridge.	No salt bridge is needed.
6) Cathode is + ve and anode is -ve	Cathode is – ve and anode is + ve.

**Galvanic cell:** A typical example of galvanic cell is Daniel cell, which is illustrated in the fig.



The above observations are explained by the following oxidation-reduction reactions taking place at anode and cathode respectively.



By convention, the electrode at which oxidation occurs is anode and the electrode where reduction occurs is cathode. In a galvanic cell anode is negative and cathode is positive. The flow of electrons is from zinc electrode to copper electrode. Hence the flow of conventional current is from copper electrode to zinc electrode.

The net redox reaction, called electrochemical reaction, is the cause for production of electricity. The net reaction is the sum of two electrode reactions and is called cell reaction. Each electrode reaction is called as half-cell reaction.

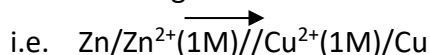
**Salt bridge:** It is easy to construct. A thin paste of agar-agar in water is added to boiling water containing a little of an electrolyte like KCl or  $\text{KNO}_3$ . It is then drawn preferably into U- tube and cooled.

**Function:** The salt bridge not only connects the two half-cells internally. It maintains the electrical neutrality of both the half cells and is used to complete the circuit.

- Note:** 1. When one of the solutions contains soluble silver, mercurous or thallous salt, the KCl salt bridge cannot be employed.
2. KCl or  $\text{KNO}_3$  is used because the ions have almost same migration velocities.

### Cell notation and sign conventions:

The following notation is used to represent the Daniel cell.



- Single vertical line / a phase boundary between metal and its solution.
- Double vertical line // salt bridge
- Arrow indicates direction of flow of electrons
- Concentration of the solutions must be written in parentheses.

**Sign conventions:** The half cell at which oxidation (Anode) occurs is always written on the left side and the half cell at which reduction (cathode) occurs is always written on the right side

- The concentration of solutions, pressure of gases and physical state of the solid or liquid involved are indicated by suitable signs within brackets.
- If the arrow is in the forward direction i.e, the electrons are flowing from anode to cathode the emf of the cell is positive. If the arrow mark is in backward direction the electrons flow from cathode to anode the emf of the cell is negative.
- Anode to be represented as  $\text{M}/\text{M}^{n+}$  and cathode in the form  $\text{M}^{n+}/\text{M}$ .
- The term electrode potential refers the reduction potential. It is represented as  $E_{\text{M}^{n+}/\text{M}}$
- The potential difference between the two electrodes, called EMF (Electro Motive Force), is stated in volts. Ex:  $E_{\text{cell}} = E_{\text{cathode}} - E_{\text{anode}}$ .

**Electrochemical series:** Metals are arranged in the increasing order of their standard reduction potential with respect to hydrogen scale.

Electrode or Metal	Standard reduction potential
Li	- 3.05
K	- 2.93
Ca	- 2.87
Mg	- 2.36
Al	- 1.66
Mn	- 1.18
Zn	- 0.76
Fe	- 0.44
Ni	- 0.23
Pb	- 0.18
Sn	- 1.14
H	0
Cu	+ 0.34
Ag	+ 0.80
Pt	+ 1.2
Au	+ 1.69

## ENERGY CONVERSION SYSTEMS

**BATTERY:** A battery is a device that consist of two or more galvanic cell connected in series or parallel or both, which converts chemical energy into electrical energy through redox reaction.

Example: Lead acid battery, Lithium ion battery, Nickel-Cadmium battery etc.

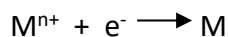
**Uses:** Batteries are used in calculators, watches and hearing aids, computers, car engines, emergency lightning in hospitals, military and space applications.

**Basic Components of Battery:** The battery consists of four major components.

**Anode** (Negative electrode): It releases electrons into the external circuit by undergoing oxidation.



**Cathode** (Positive electrode): It accepts electrons coming from anode through external circuit.



**Electrolyte:** It provides the medium for transfer of ions inside the cell between the anode and cathode. A solution of an acid, alkali or salt having high ionic conductivity is commonly used as an electrolyte.

**Separator:** It is used to separate anode and cathode compartments in a battery to prevent internal short circuiting. It allows the ions from anode and cathode. Ex: Cellulose, naflon membranes.

### Classification of battery:

The batteries are classified as

1. **Primary battery:** A battery which cannot be recharged, cell reactions are irreversible and discarded when the battery has delivered all its electrical energy. Eg: dry cell or Zn-MnO<sub>2</sub> Cell, Li-MnO<sub>2</sub> cell.
2. **Secondary battery:** A battery which can be recharged, cell reactions are reversible and A battery which after discharging, can be recharged. Eg: Lead storage and nickel cadmium cell.
3. **Reserve battery:** In reserve batteries, one of the components is stored separately and is incorporated into the battery when required. Eg: Mg-AgCl and Mg-CuCl battery.

### Li-ion battery: (Secondary battery)

#### Construction:

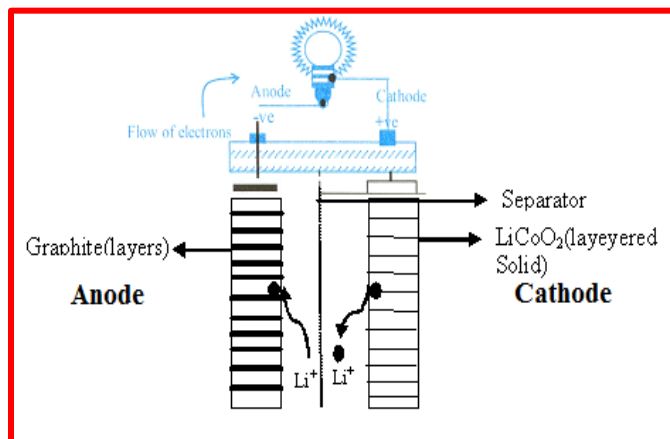
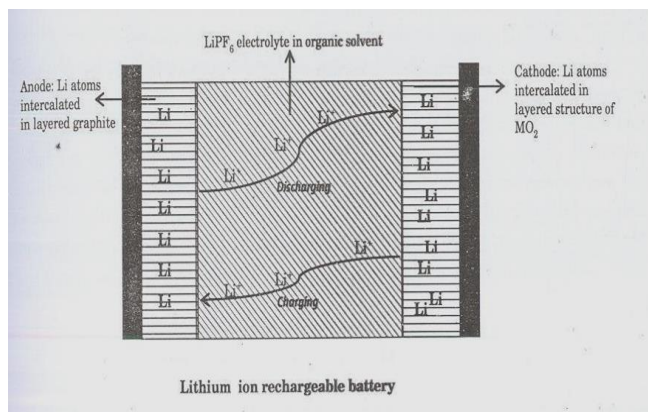
**Anode:** Lithium atoms intercalated in layered graphite / Carbon metal

**Cathode:** Lithium atoms intercalated in layered structure of MO<sub>2</sub>

**Electrolyte:** The electrolyte is lithium salt such as LiPF<sub>6</sub> dissolved in organic solvents (Ethylenecarbonate – dimethyl carbonate)

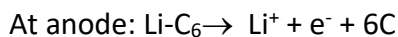
**Separator:** Made of Poly propylene membrane.

**Cell representation:** Li | Li<sup>+</sup>, C/ LiPF<sub>6</sub> in organic solvents | Li-MO<sub>2</sub>

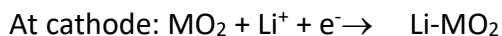


### Electrode reactions are:

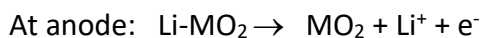
**During discharging**, lithium atoms present in graphite layer are oxidized, liberating electrons and lithium ions. Electrons flow through external circuit to cathode and lithium ions flow through the organic electrolyte towards cathode.



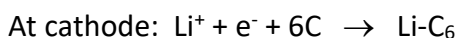
At cathode, lithium ions are reduced to lithium atoms and are inserted into the layered structure of metal oxide.



**During charging**, lithium atoms present in layered structure of metal oxide are oxidized, liberating electrons and lithium ions. Electrons flow through external circuit and lithium ions flow through the organic electrolyte towards graphite carbon electrode.



At graphite electrode, lithium ions are reduced to lithium atoms and are inserted into the layered structure of graphite.



### **Applications:**

1. The Li-ion batteries are used in cameras, calculators.
2. They are used in cardiac pacemakers and other implantable device.
3. They are used in telecommunication equipment, instruments, portable radios and TVs, pagers.

4. They are used to operate laptop computers and mobile phones and aerospace application.

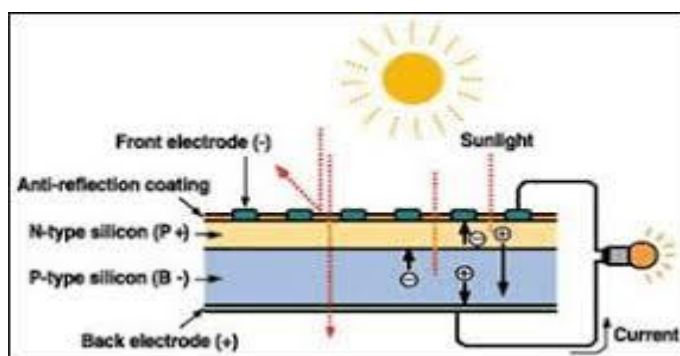
### Solar Energy:

**Introduction:** Photovoltaic cells are semiconductor device which converts light or solar energy into electrical energy and it works on the basis of photoelectric effect.

### **Construction and Working of Photovoltaic Cell:**

**Construction:** A typical silicon photovoltaic cell is composed of a thin wafer consisting of an ultra thin layer of Phosphorous doped (n-type) silicon on top and Boron doped (p-type) silicon at the bottom.

Hence a p-n junction is formed between the two. A metallic grid above the diode forms one of the electrical contact and allows the light to fall on the semiconductor. The anti reflective layer (silicon nitride or  $\text{TiO}_2$ ) present in between the metallic grid increases the transformation of sunlight to a semiconductor. The other metallic layer at the back of the semiconductor forms another electrical contact.



**Working:** When the electromagnetic radiations fall on the p-n junction diode, electron and hole pair are generated. Electrons move and collect at the n-type end and the holes move towards the p-type end. On connecting these two ends through conductor current flows between them to an external circuit.

### Applications:

- Rooftop and building integrated systems
- smart sensors and communication devices
- One of the most cost effective solar applications is a solar powered pump, as it is far cheaper to purchase a solar panel than it is to run power lines
- Solar street lights
- Rural electrification
- In remote locations in India a rural lighting program has been providing solar powered LED lighting to replace kerosene lamps.

### Quantum dot sensitized solar cells (QDSSC's)

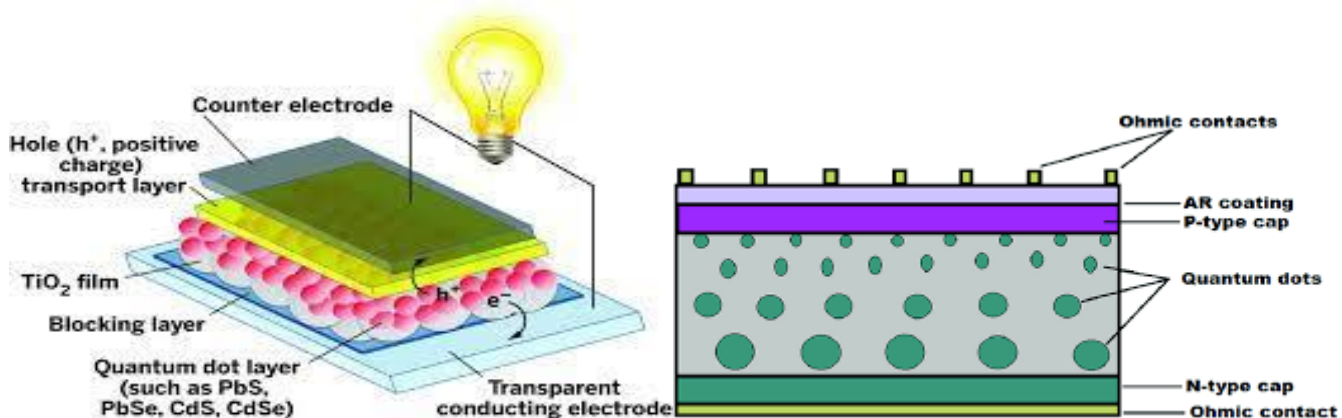
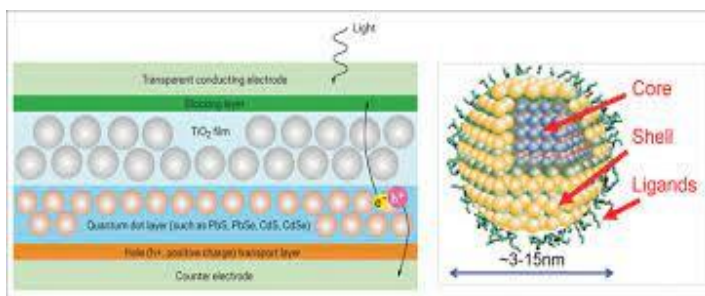
Quantum dots are semiconductor nanoparticles that glow a particular color after being illuminated by light. A Quantum dot solar cell (QDSC) is a solar cell that uses quantum dots as the captivating photovoltaic material. It is used to replace bulky materials such as silicon, or copper, indium, gallium and selenide.

Quantum dots have band gaps that are adjustable through a wide array of energy levels by changing the size of the dots.

**NOTE:** A new type of quantum dot could lead to cheaper solar cells and better satellite.

### Principle:

The light rays enter through the transparent electrode of a quantum dot solar cell onto a light absorbing layer of dots in order to generate electron-hole pairs. The charged particles then separate eventually travel to their respective electrodes, producing electric current.



### Properties:

- Tuned physico-chemical properties
- Interesting optical properties
- QDSSC's have high moisture & thermal stability
- High absorption co-efficient
- Opto-electronic properties change as a function of both size & shape
- Quantum dots are colloidal fluorescent semiconductor nanocrystals.

### Applications:

- It is used to construct a large panel displays
- PV cells
- Quantum Computation
- Photo detectors and conductors
- Light emitting diodes

- Detection of genetic disease