Unit - 3. Battery Technology

Introduction to Electrochemical Cell:

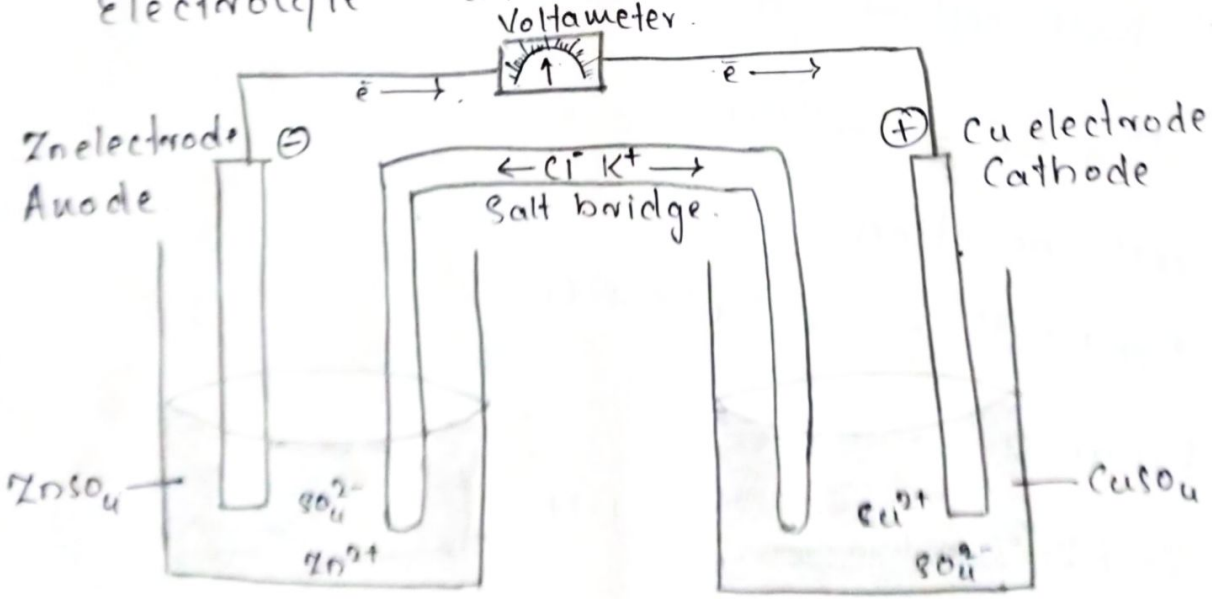
- Electrochemical cells are devices which utlizes the electric current chemical energy and converts to electric energy.
- It is also called as voltaic / galvanic cells.
- It comprises electrodes and electrolyte

Electrodes: Anode - Negative Potential
Cathode - Positive Potential.

Oxidation takes place at anode (loss of $\bar{e}$)

Reduction takes place at cathode (gain of $\bar{e}$)

Electrolyte conducts the ions.



Electrochemical cell

Daniel Cell

Daniel Cell:

- Consists of Zinc electrode dipped in $ZnSO_4$ solution which acts like half cell.
- In this Zn-half cell oxidation takes place.
- Copper electrode is dipped in $CuSO_4$ solution acting like a another half cell where reduction occurs.
- Two half cells are separated by salt bridge (KCl).

Electrode Reactions:

1st half cell → Anode - Oxidation.

$$Zn \longrightarrow Zn^{2+} + 2e^-$$

2nd half cell → Cathode - Reduction

$$Cu^{+2} + 2e^- \longrightarrow Cu$$

Net cell reaction.

$$Zn + Cu^{+2} \longrightarrow Zn^{+2} + Cu$$

Cell Representation.

$$Zn / Zn^{2+}(1M) \;||\; Cu^{2+}(1M) / Cu$$

EMF of cell = $E_{cell} = E_{right} - E_{left}$

$$E_{cell} = E_{cathode} - E_{left}$$

The positive Ecell value indicates reaction is feasible (Spontaneous).

$\Delta G = -nFE$.

For a battery if $\Delta G < 0$. means negative, the battery is capable of doing work

Battery : Introduction:

- Batteries are storehouse of electrical energy.
- They store chemical energy for later release as electricity
- Battery is made up of number of electrochemical cells connected in series that can be used as a source of direct electric current at a constant voltage.
- Battery acts like a portable source of electrical energy.

Types of Batteries.:

1) Primary Batteries or Primary cells.
2) Secondary Batteries or secondary cells.
3) Fuel Batteries or Fuel cells.

Primary Batteries:

- Primary batteries are those which are designed to be used once and discarded.
- Primary batteries can not be recharged with electricity.
- The electrochemical reaction occuring in the cell is not reversible (Irreversible).
- Primary batteries are unrechargable.
- When all the reactants are converted into products no more electricity is generated. & the battery becomes dead.
- These are used as a source of DC power.

Ex: * Lithium cell.

* Laclanche cell.

Secondary Batteries:

- Secondary Batteries are type of electrical battery which can be charged, discharged into a load & recharged many times.
- The electrochemical reaction occuring in the cell is reversible.
- The cell reaction can be reversed by passing direct current in opposite direction.
- Secondary batteries are rechargable.
- These can be used as a primary battery, then recharged & used again.
- It contains large number of charge/discharge cycle.
- These are reversible behave as galvanic cells while discharging and behaves as electrolytic cells while charging.

Ex: Lead-acid batteries

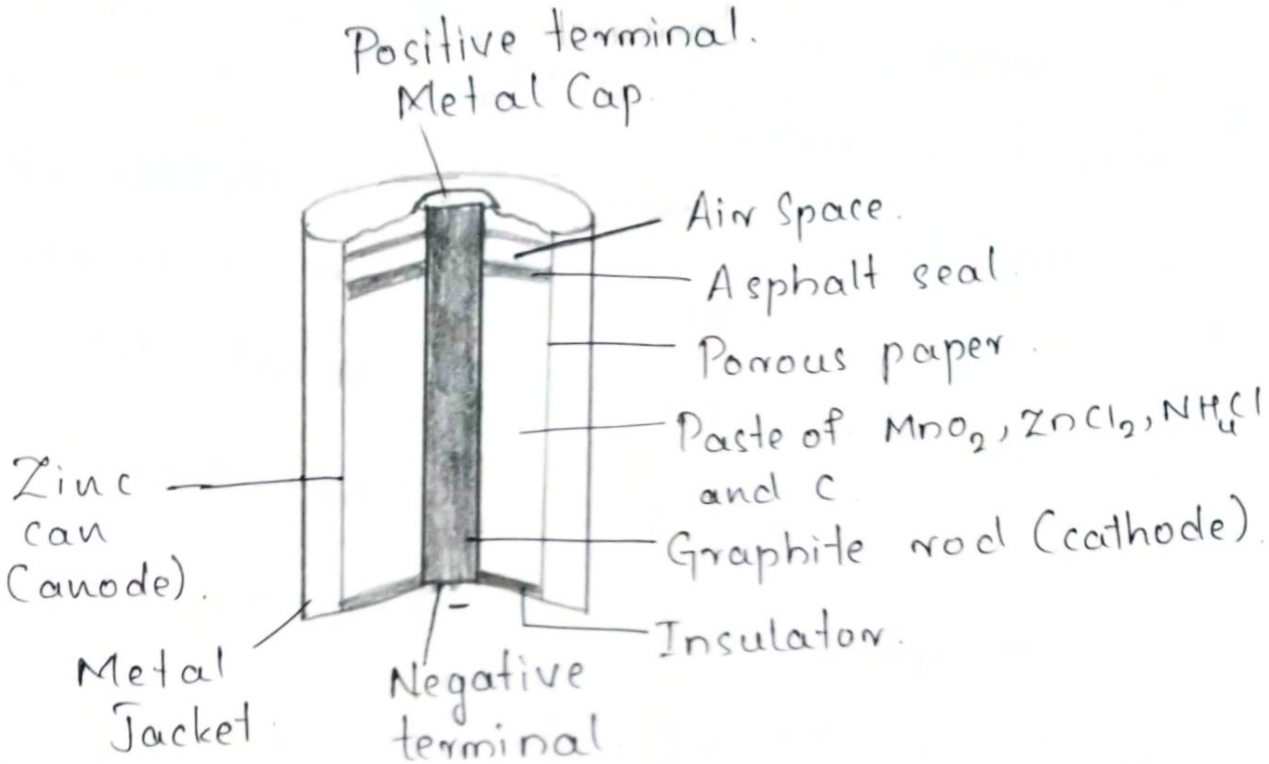
Lithium-ion batteries.

Dry / laclanche cell :

- It consists of cylindrical Zn container which acts as a anode.
- A graphite rod placed in the center but not touching the base acts as the cathode.
- The space between anode & cathode is filled with a paste of NH_4Cl & $ZnCl_2$.
- The Graphite rod is surrounded by powdered MnO_2 & carbon.
- The cell is called as Dry because of absence of any liquid phase.
- The electrolytes NH_4Cl, $ZnCl_2$ & MnO_2 are mixed with starch to make a thick paste to prevent leakage.
- The graphite rod is fitted with metal cap, & cylinder is sealed at the top.

Dry cell is represented as.

$Zn/Zn^{2+}, NH_4^+, MnO_2/C$ EMF = 1.5 Volts.



Cell Reactions:

Anode : Oxidation $Zn(s) \longrightarrow Zn^{2+}(aq) + 2e^-$

Cathode : Reduction $2MnO_2(s) + H_2O + 2e^- \longrightarrow Mn_2O_3(s) + 2OH^-(aq)$

The resulting OH^- ions react with NH_4^+ ions. derived from NH_4Cl to produce ammonia NH_3. This is not liberated as gas, instead it immidiately reacts with Zn^{2+} & Cl^- ions to form a complex salt $[Zn(NH_3)_2]Cl_2$, diamine. dichloro zinc.

Overall Reaction:

anode: $Zn(s) \longrightarrow Zn^{2+}(aq) + 2e^-$

cathode: $2MnO_2(s) + H_2O + 2e^- \longrightarrow Mn_2O_3(s) + 2OH^-(aq)$.

Net Reaction $Zn(s) + 2NH_4^+(aq) + 2Cl^-(aq) + 2MnO_2(s) \longrightarrow$

$Mn_2O_3(s) + [Zn(NH_3)_2]Cl_2(s) + 2H_2O$.

Advantages:

1) They are low cost & gives a voltage of about 1.5 volts.
2) Uses - flash lights, transistor radios, calculators, pacemakers, hearing aids, toys. etc.

Disadvantages:

1) When current is drawn rapidly, products of reaction gets deposited on electrodes thereby causing drop in voltage.
2) Life of dry cell is short.

Lead - Acid Battery (Secondary Battery).

- In general lead - acid battery are of 12 Volts. which consists of six cells having 2 V each.
- Each cell consists of a lead anode & a grid of lead packed with lead oxide which acts as cathode.
- These electrodes are arranged alternately, separated by thin wooden piece & suspended in dil. H_2SO_4 (38%) which acts as an electrolyte.
- Hence, it is called as lead - acid battery.

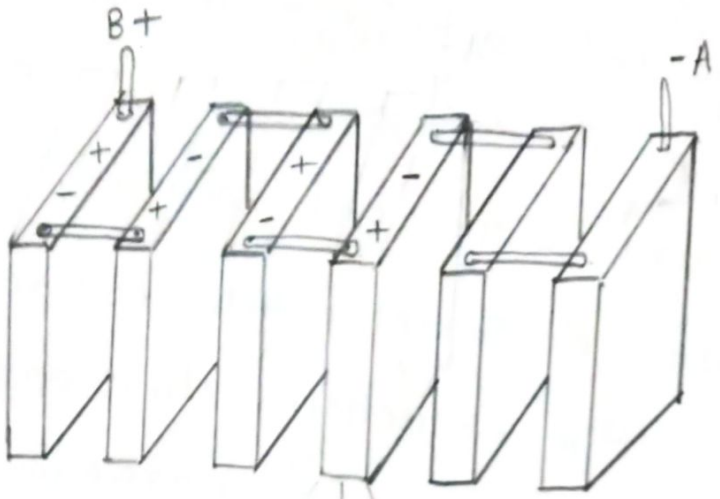
- Anode → lead.
  Cathode → lead oxide.
  Electrolyte → dil. H_2SO_4.
  EMF → 12 V.

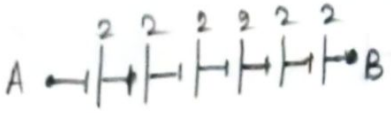
Cell Representation:

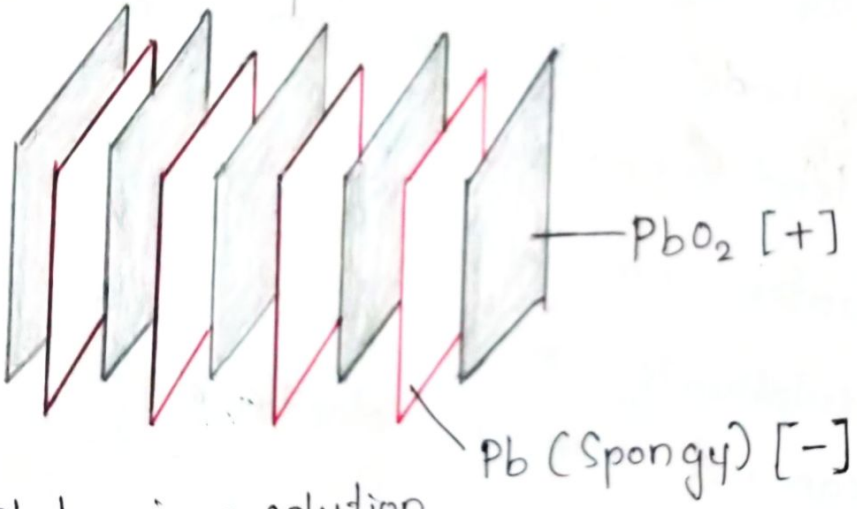
$$Pb \mid PbSO_4(s) \mid H_2SO_4(40\%) \mid PbO_2(s) \mid Pb$$

Anode — Cathode.

Diagram:







Plates in a solution of H_2SO_4 and H_2O.

Cell Reaction:

Anode: (Oxidation): $Pb + SO_4^{2-} \longrightarrow PbSO_4(s) + 2e^-$.

Cathode: (Reduction): $PbO_2(s) + 4H^+ + SO_4^{2-} + 2e^- \longrightarrow PbSO_4(s) + 2H_2O$.

Net cell Reaction: $Pb + PbO_2(s) + 2SO_4^{2-} \longrightarrow 2PbSO_4(s) + 2H_2O + Energy$.

Discharging of lead-acid battery:

- During use (discharging), both the electrodes of lead storage cell gets coated with white precipitate of lead sulphate.
- And the sulphuric acid gets diluted.
- When both the electrodes gets covered with lead sulphate, the reaction stops, the cell is said to be dead or discharged.
- In fully discharged state, anode - lead (Pb) and cathode (PbO_2) are completely converted into lead sulphate ($PbSO_4$).
- The water produced in the cell, dilutes the sulphuric acid. Under this condition cell can not supply electricity.

Discharge reaction:

anode - Oxidation → $Pb + SO_4^{2-} \longrightarrow PbSO_{4(s)} + 2e^-$

cathode - Reduction → $PbO_{2(s)} + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_{4(s)} + 2H_2O$

Net reaction → $Pb + PbO_{2(s)} + 2SO_4^{2-} + 4H^+ \longrightarrow 2PbSO_4 + 2H_2O + Energy$

The discharged storage cell can be recharged by passing direct current (DC).

Recharging of lead-acid battery:

- Recharging is done by supplying DC.
- The direct current reverses the electrode reactions, & converts the lead sulphate back to lead & lead oxide on the respective electrodes.
- During charging, the negative electrode of lead acid cell is connected to the negative of the DC source, and the positive electrode is connected to the positive of the DC source.

Recharging Reaction:

Anode - $PbSO_4(s) + 2e^- \longrightarrow Pb(s) + SO_4^{2-}(aq)$ - reduction.

Cathode - $PbSO_4(s) + 2H_2O \longrightarrow PbO_2(s) + 4H^+ + SO_4^{2-} + 2e^-$ - oxidation.

Net Reaction - $2PbSO_4(s) + 2H_2O + Energy \rightarrow Pb(s) + PbO_2(s) + 4H^+ + 2SO_4^{2-}$

During recharging the electrode materials are converted back to their original forms, & the cell once again starts generating electricity.

Advantages:

1) They are rechargable, portable & provide a constant voltage (potential).
2) They are low cost.
3) Used in hospitals, laboratories, UPS, railways etc.

Disadvantages:

1) Use of corrosive acid - H_2SO_4

Lithium - Ion Battery: (Li-ion)

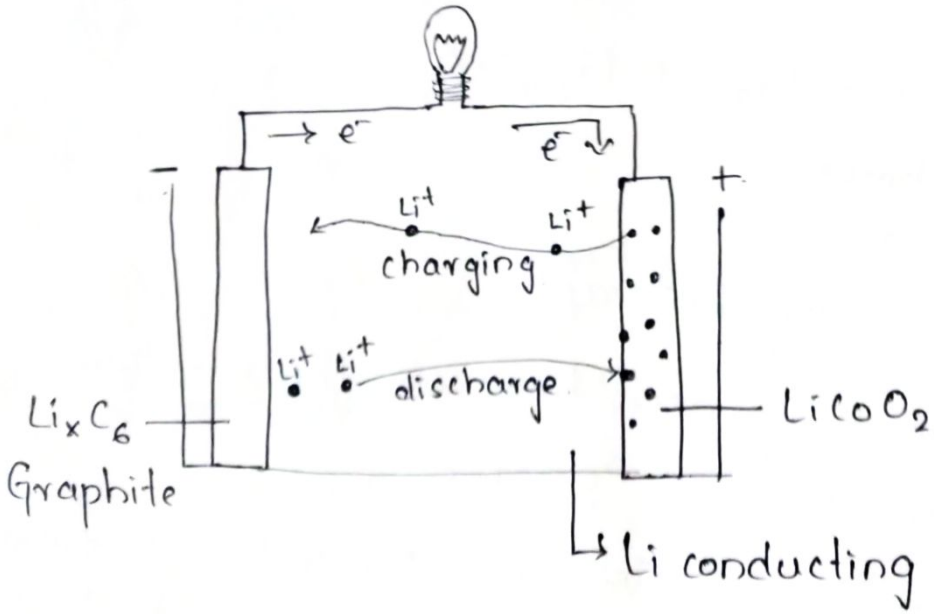
- Li-ion Battery is a secondary battery, means its a rechargable battery.
- It is advanced battery which uses Li-ion as component.
- Anode - Is made up of Graphite.
- Cathode - Is made up of Lithium cobalt oxide (or) Lithium manganese oxide.
- Li-ion batteries use an intercalated lithium compound, which is rechargable battery. Where as in Li-batteries if metallic Lithium is used it is a non-rechargeable lithium battery.

["Intercalated Lithium batteries means, Li-ion are tied to an electron within the structure of anode."

Intercalation means when charged ions of an element can be held inside the structure without significantly disturbing it.]

- Both the electrodes allow lithium ion to move in and out of their interiors.
- During Insertion (intercalation) ions move into the electrode.
- During reverse process, extraction (deintercalation) ions move back out.

Lithium ion Battery



Cell Reaction:

Positive electrode -

$$LiCoO_2 \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_{1-\alpha}CoO_2 + \alpha Li^+ + \alpha e^-$$

Negative electrode -

$$C + \alpha Li^+ + \alpha e^- \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_x C$$

Overall Reaction.

$$LiCoO_2 + C \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_\alpha C + Li_{1-\alpha}CoO_2$$

Advantages of Li-ion Battery:

1. Has highest energy densities of any battery technology today.
2. Li-ion battery can deliver 3.6 Volt, 3 times higher than Ni-Cd.

~~- low maintance.~~

- low maintenance.
- Li-ion batteries have no memory effect, a detrimental process where repeated partial discharge & charge cycles can cause a battery to remember a lower capacity. This is advantage over both Ni-Cd and Ni-MH, which display this effect.
- Li-ion batteries also have low self discharge rate of around 1.5-2% per month.
- They do not contain toxic metals like cadmium, which makes them easier to dispose.
- They have potential applications in battery-powered cars.

Disadvantages / Limitations of Li-ion Battery:

- Li-ion batteries have a tendency to overheat, and can be damaged at high voltages.
- Overcharging, overheating or short-circuiting a charged Li-ion battery can result into fire or explosion.

- Cost is around 40% higher than Ni-Cd.
- Li-ion batteries are also subject to aging, meaning that they can lose the capacity & frequently fail after a number of years.

Fuel Cell:

- Fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity, and forms water and heat as by-product.

Principle: In fuel cells, the fuel and oxidant are stored outside the cell. The fuel and oxidant are supplied continuously & separately to the electrodes at which they undergo redox reactions.

- Conversion of fuel to energy takes place without combustion.
- This process is clean, quiet & highly efficient.

Fuel + Oxidant ⟶ Oxidation Products + Electric current.

Ex: H_2-O_2 fuel cell, Polymer electrolyte membrane fuel cells.
Alkaline fuel cell (AFC) used in NASA,
Phosphoric acid fuel cell (PAFC). etc.
Direct methanol fuel cells,

- Functioning of fuel cell is based on Electrolysis and reverse electrolysis.
- Energy from the battery splits water into H_2 & O_2.
- Combination of H_2 & O_2 produces water & releases energy.

Basics of Fuel Cells:

Anode: Fuel reacts (oxidised) and releases electrons.

Cathode: Where oxygen (usually from the air) undergo reduction.

Electrolyte: A chemical compound that conducts ions from one electrode to other.

In fuel cell anode & cathode are sandwiched around an electrolyte. A fuel such as hydrogen, is fed to anode and air is fed to cathode. The electrolyte or catalyst in fuel cell separates hydrogen atom into proton.

and electrons, which takes a path to cathode.

- Electrons go through an external circuit, creating a flow of electricity.
- The Proton migrate through the electrolyte to the cathode, where they reunite with oxygen and the electrons to produce water and heat.

$H_2 - O_2$ Fuel cell:

- Most simple and efficient fuel cell.
- The reaction between hydrogen & oxygen can be used to generate electricity via. fuel cell.
- Such cell was used in Apollo space pragramme and it served two different purpose.
  i) It was used to source of fuel as well as source of water.
- Consists of two inert porous electrodes made of graphite soaked with finely divided 'pt' or 'Ni' and a solution of 25% KOH as electrolyte sandwiched between two electrodes.

* Hydrogen is fed to anode electrode
* Air is fed to cathode electrode.
* The catalyst separates hydrogen atoms into protons & electrons. Both proton & electron travel to cathode, but in different path.
* Electrons go through an external circuit, creating a flow of electricity.
* Protons go migrate through the electrolyte then to cathode
* At cathode they reunite with oxygen & electrons to produce water & heat.

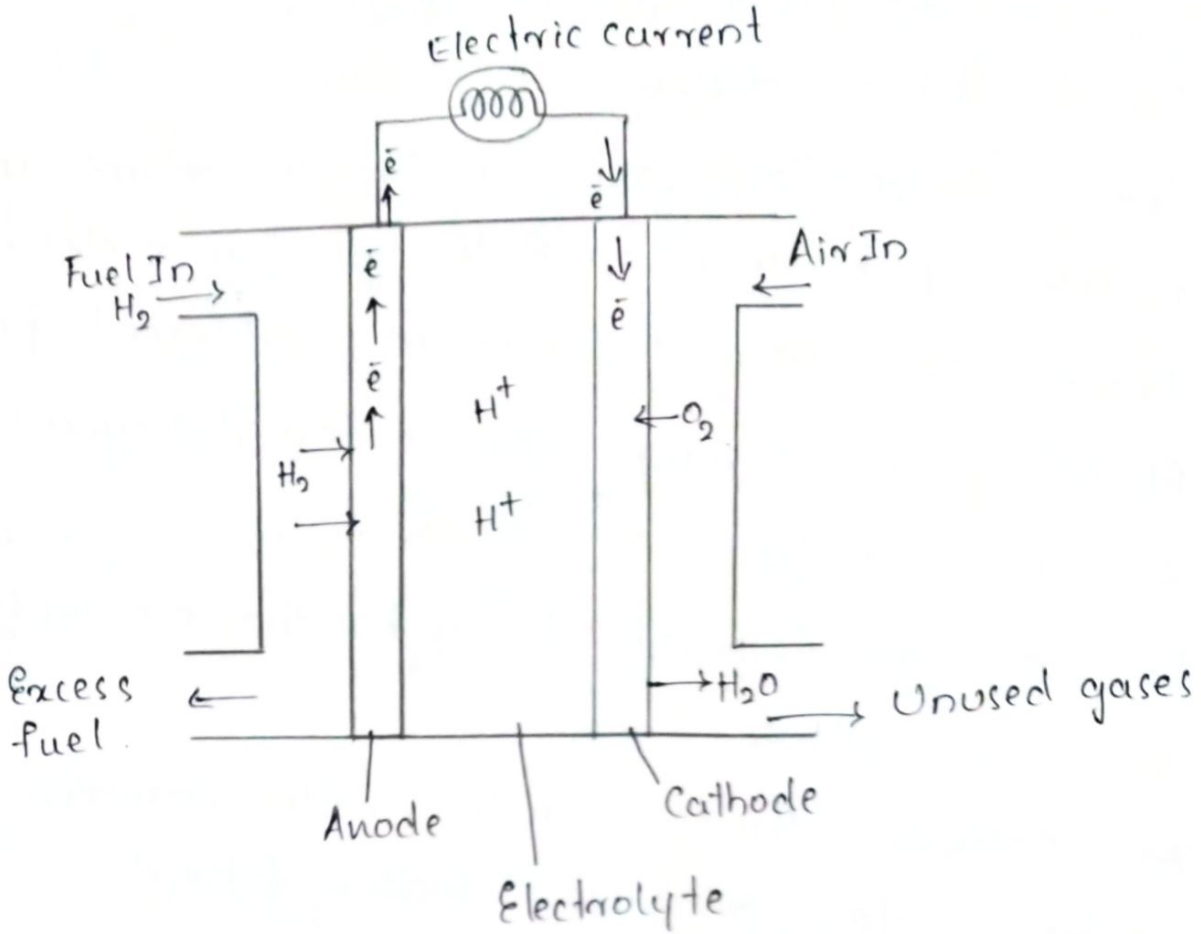
Cell Reaction:

Anode - $2H_2(g) + 4OH^- \longrightarrow 4H_2O + 4e^-$

Cathode - $O_2(g) + 2H_2O + 4e^- \longrightarrow 4OH^-$

Net Reaction - $2H_2(g) + O_2(g) \longrightarrow 2H_2O$ $E_{cell} = 1.23\ V.$

A large number of these cells are connected in series to form a fuel cell.



Phosphoric Acid Fuel Cell (PAFC):

- A phosphoric acid fuel cell consists of an anode and a cathode made of a finely dispersed platinum catalyst on carbon.
- A silicon carbide structure holds the phosphoric acid electrolyte.
- In phosphoric acid fuel cells, protons move through the electrolyte to the cathode to combine with oxygen and electrons, producing water and heat.

- Used for stationary power production in hotels, hospitals, grocery stores and office buildings, where waste heat can also be used.

Cell Reaction:

Anode: $H_2 \longrightarrow 2H^+ + 2e^-$

Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \longrightarrow H_2O$.

Limitations of PAFC:

- Cells are large & heavy
- Platinum required is very costly.
- Less pl powerful than H_2-O_2 fuel cell.
- Generally used for stationary power source.
- Efficiency is not very high.

Advantages of fuel cell:

1. Fuel cells have high efficiency, nearly about 70%. While other sources have 15 to 20% efficiency (Gasoline engine) & 30-35% (diesel engine.

2. The efficiency of the fuel cell does not depend on the size of the power plant.

3. Maintance cost is very low.

4. Fuel cells are more efficient in producing the mechanical power to drive the vehicles. and require less energy consumption.

Disadvantages:

1. Initial cost of fuel is high.

2. Life span of fuel cell is not known accurately.

3. There is a problem of durability & storage of large amount of hydrogen.

Distinction between Primary, Secondary & Fuel cell.

Primary	Secondary	Fuel Cell
* A simple galvanic or voltaic cell that produces electricity.	Acts as galvanic or voltaic cell while discharging electricity and as electrolytic cell while charging	- A simple galvanic or voltaic cell that produces electricity.
* Cell reaction is irreversible	Cell reaction is reversible	- Cell reaction is reversible.
* Cell cannot be recharged	Cell can be recharged	- Energy can be withdrawn continuously.
* Can be used as long as active materials are present	Can be used again & again by recharging	- Reactants have to be continuously replenished, it does not store energy
* Ex: Laclanche cell or dry cell. Lithium cell.	Ex: lead-acid battery, Lithium ion cell.	Ex: H_2 & O_2 fuel cell AFC, PAFC.
Uses: Watches, Calculators,	Uses: Automobiles, electronic equipment etc.	Uses: In space vehicles due to light weight.

Types of fuel cells:

* Polymer electrolyte membrane fuel cell.
* Direct methanol fuel cell.
* Alkaline fuel cell.
* Phosphoric acid fuel cell.
* H_2-O_2 fuel cell.
* Molten carbonate fuel cell.
* Solid oxide fuel cell.
* Combined heat and power fuel cell.
* Regenerative or reversible fuel cells.