

Unit I

Electrochemistry, Energy Conversion and Storage Devices

Electrochemistry: Introduction. Types of electrodes: metal-metal ion, metal-metal salt ion, gas, amalgam, redox & ion selective. Reference electrodes: Introduction; construction, working and applications of calomel and Ag / AgCl electrodes. Construction and working of glass electrode, determination of pH using glass electrode.

Battery Technology: Introduction, Characteristics - cell potential, current, capacity, electricity storage density, energy efficiency, cycle life and shelf life. Construction, working and applications of Zinc-Air, Nickel- metal hydride batteries and Li-ion batteries. Fuel Cells: Introduction, difference between conventional cell and fuel cell, limitations & advantages. Classification of fuel cells based on electrolyte; construction & working of polymer electrolyte membrane fuel cell. Numerical problems on batteries.

Photovoltaic cells: Importance, construction and working of photovoltaic cells. Design: modules, panels & arrays. Production of solar grade silicon by Union carbide process.

Introduction

An important aspect of electrochemistry is the inter conversion of electrical energy and chemical energy that take place through oxidation- reduction (redox) reactions. Redox reactions form the basis of electrochemical cells. The development of theoretical concepts of electrochemistry was accompanied by practical applications such as electroplating, electroextraction of metals, electrorefining of metals etc. Electrochemical principles helped in understanding the corrosion of metal and in combating it efficiently.

Electrochemical cells are of two types; i) Galvanic cells and ii) Electrolytic cells.

- i) A galvanic cell is an electrochemical cell in which chemical energy is converted into electrical energy. Electric current is generated due to spontaneous reaction occurring inside the cell. Dry cell, lead storage battery and nickel cadmium cell are the examples Galvanic cell.
- ii) A cell which converts electrical energy into chemical energy is called electrolytic cell. In an electrolytic cell electrical energy is supplied from an external source so as to bring about a non-spontaneous chemical change.

Single Electrode Potential

"It is defined as the potential developed due to the tendency of a metal electrode either to lose or gain electrons when it is in contact with the solution of its own ions."

Types of Electrodes

Various electrodes are used in electrochemical applications based on the purpose. The following are some of the important types of electrodes.

- 1) **Metal-metal ion electrode:** In this type of electrode, a metal is in contact with its ionic solution. Ex; Zn/Zn^{+2} , Ag/Ag^{+} etc.
- 2) **Metal-Metal insoluble salt electrode:** In this type of electrode, a metal is in contact with a sparingly soluble salt of the same metal dipped in solution containing anion of the metal salt. Ex; Calomel electrode, $\text{Ag}-\text{AgCl}$ electrode.
- 3) **Gas Electrode:** In this type of electrode, gas is in contact with an inert metal dipped in an ionic solution of gas. Ex: Hydrogen electrode ($\text{Pt}/\text{H}_2/\text{H}^{+}$)
- 4) **Amalgam electrode:** In this type metal-amalgam is in contact with a solution containing its own metal ions. When the pure metals are too active to use them in aqueous solution they are used in the form of amalgam. Ex; $\text{Pb}-\text{Hg}/\text{Pb}^{+2}$
- 5) **Redox electrode:** In this type of electrode oxidized and reduced forms of same substance are in contact with an inert electrode like platinum/ gold/ carbon.
Ex; $\text{Pt}/\text{Fe}^{+3}, \text{Fe}^{+2}$
- 6) **Ion-selective electrodes:** In this type of electrode, a membrane is in contact with an ionic solution with which it can exchange selective ions. Ex: Glass electrode

Reference Electrodes

“The electrode of fixed potential or constant potential, with reference to which the potential of any other electrode can be measured, is called reference electrode.”

There are two types of reference electrodes, namely

1. Primary reference electrode, Example: Standard hydrogen electrode (SHE)
2. Secondary reference electrode, Example: Calomel electrode and silver-silver electrode

The electrode potential of standard hydrogen electrode is taken as zero at all temperatures. The electrode potential of any other electrode can be measured by coupling with standard hydrogen electrode.

Limitations of Primary Reference Electrode

- i) The electrode construction is cumbersome.
- ii) It is difficult to maintain the pressure of hydrogen gas at 1 atmosphere and unit concentration of the solution.
- iii) The electrode gets easily poisoned by the presence compounds such as Hg, As, S etc
- iv) The electrode cannot be used in the presence of oxidizing agents

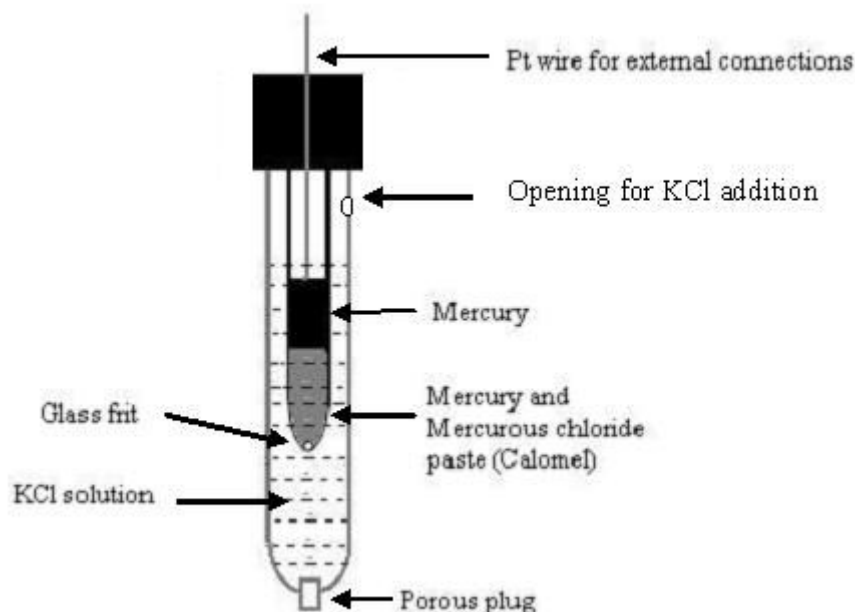
Secondary Reference Electrodes

To overcome the limitations of standard hydrogen electrode as reference electrode, there was a need for the development of secondary reference electrodes. "Electrodes whose potential is known with respect to standard hydrogen electrode and with reference to which the potential of any other electrode can be measured" are referred as secondary reference electrodes. These electrodes can be easily set up. Ex: Calomel electrode, Silver-silver chloride electrode.

Calomel electrode

The **calomel electrode** is a metal - metal salt ion electrode, in which the mercury is in contact with its insoluble salt mercurous chloride and in turn in contact with the anion of the salt.

The calomel electrode is symbolically represented as,



Construction:

It consists of an inner tube with a porous plug at the bottom. Hg_2Cl_2 is placed at the bottom of the inner tube and above which mercury is placed. The Pt wire is in contact with the mercury and used for electrical contact. This tube is placed in an outer tube containing solution of KCl having porous plug at the bottom, which serves as a salt bridge. An opening is provided in the outer tube for the addition of KCl.

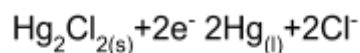
The electrode can act as an anode or cathode depending on the nature of the other electrode of the cell

The electrode reactions represented as follows:

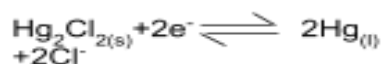
As Anode



As Cathode



The net reversible reaction is,



Since, the calomel electrode is reversible with respect to chloride ions its electrode potential depends upon the concentration of KCl solution.

The electrode potential may be represented by the Nernst equation as,

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

The electrode potentials are as follows,

0.1N KCl	E=0.334V
1N KCl	E=0.280V
Saturated KCl	E=0.242V

Applications

- i) It is used as a secondary reference electrode in the measurement of single electrode potential.
- ii) It is used as a reference electrode in all potentiometric determinations.

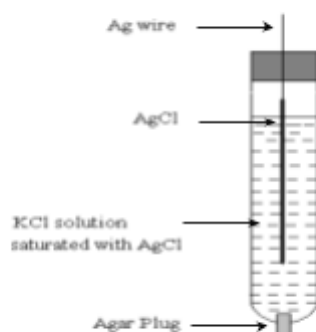
Silver-Silver Chloride Electrode

It is a metal-metal insoluble salt electrode, where silver is in contact with its sparingly soluble salt silver chloride and the solution contains the anion of the salt, Cl^- .

The silver – silver chloride electrode is symbolically represented as,



It is prepared by depositing a thin layer of AgCl electrolytically on a silver wire and is then immersed in a solution containing Cl^- ions.



The electrode reaction is represented as $\text{AgCl}_{(s)} + e^- \rightleftharpoons \text{Ag}_{(s)} + \text{Cl}^-$

Since, the silver – silver chloride electrode is reversible with respect to chloride ions its electrode potential depends upon the concentration of KCl solution.

Applying Nernst equation.

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

For 0.1 N KCl solution $E = 0.260 \text{ V}$

For 1 N KCl solution $E = 0.223 \text{ V}$

For Saturated KCl solution $E = 0.199 \text{ V}$ at 298 K

Applications

- i) It is used as a secondary reference electrode in the measurement of single electrode potential.
- ii) It is used as a reference electrode in all potentiometric determinations.

Ion Selective Electrode

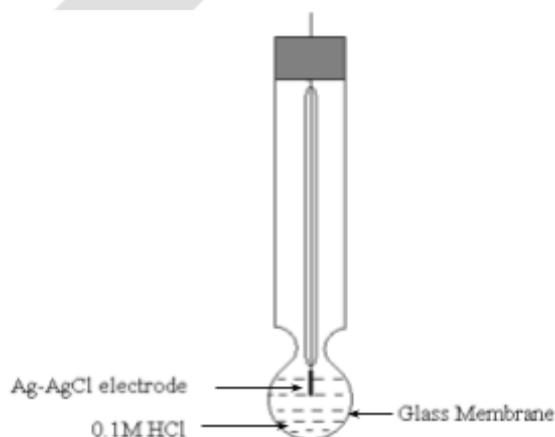
Definition: Ion selective electrode is one which selectively responds to a certain specific ions in a mixture and the potential developed at the electrode interface is a measure of the concentration of the species of interest.

Glass Electrode:

Glass electrode is a pH sensitive electrode most widely used for pH determination. The glass electrode is symbolically represented as



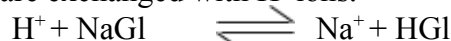
Construction:



It consists of a thin walled glass tube with a bulb at the bottom. It is made up of the special quality glass with composition of Na_2O - 22%, CaO - 6% and SiO_2 - 72%. It has high electrical conductance and can sense hydrogen ions up to pH 9. A portion of bulb is filled with solution of constant pH (0.1N HCl). A silver-silver chloride electrode dipped in the internal standard solution provides electrical contact.

Working:

The electrode is in contact with a solution of unknown pH, a potential develops between the membrane and the solution. The glass membrane undergoes ion exchange reaction, Na^+ ions are exchanged with H^+ ions.



“If the concentrations of hydrogen ions are different on either side of the glass membrane, the potential develops across the membrane. This is called boundary potential or junction potential”.

The boundary potential is given by,

$$E_b = E_2 - E_1$$

$$E_b = \frac{2.303RT}{nF} \log \frac{C_2}{C_1}$$

where C_2 is the concentration of H^+ ions of the external analyte solution into which the glass electrode is dipped and C_1 is the concentration of H^+ ions inside the bulb.

The potential developed on the glass electrode is the sum of boundary potential, potential of the internal reference electrode (E_{IRE}) and asymmetric potential (E_{asy}).
“When the concentrations of H^+ ions on the either side of the membrane are same, no potential should be developed across the membrane but practically some potential is developed. This is called asymmetric potential”

$$E_g = E_b + E_{IRE} + E_{asy}$$

$$(or) \quad E_g = \frac{2.303RT}{nF} \log \frac{C_2}{C_1} + E_{IRE} + E_{asy}$$

$$E_g = \frac{2.303RT}{nF} \log C_2 - \frac{2.303RT}{nF} \log C_1 + E_{IRE} + E_{asy}$$

For the given glass electrode, C_1 (inner reference solution, 0.1M HCl), E_{IRE} and E_{asy} are constants, called E_g^0 (standard reduction potential of glass electrode).

$$E_g^0 = -\frac{2.303RT}{nF} \log C_1 + E_{IRE} + E_{asy}$$

Therefore the above relation becomes;

$$E_g = E_g^0 + \frac{2.303RT}{nF} \log [H^+]$$

$$E_g = E_g^0 - \frac{2.303RT}{nF} \text{pH} ; \quad (\text{where } \text{pH} = -\log[H^+])$$

$$(or) \quad E_g = E_g^0 - 0.0591 \text{pH} ; \quad \text{at } 298\text{K}$$

Advantages

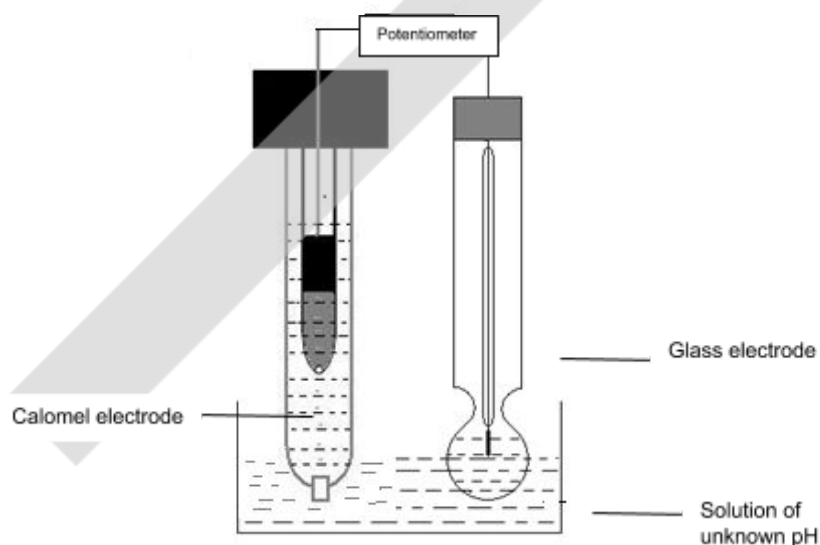
- It can be used to determine pH in the range 0-9 accurately.
- It can be used in oxidizing and reducing environment.
- The electrode does not get poisoned.
- It is simple to operate, hence widely used in portable instruments in various laboratories.

Determination of pH using Glass Electrode

The given glass electrode is dipped in the unknown solution containing hydrogen ions, constitutes a half cell. It is coupled with reference electrode (ex: calomel electrode).

The cell may be represented as:





In the above cell, the calomel electrode behaves as anode and glass electrode as cathode. The cell potential may be determined using an electronic potentiometer. The E_g^0 is determined by using standard buffer solution (known pH). E_g^0 is constant for a particular glass electrode.

The pH value of the experimental solution can be calculated by substituting the values of E_{cell} , E_{calomel} and E_g^0 in the following relation:

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

$$E_{\text{cell}} = E_{\text{glass}} - E_{\text{calomel}}$$

Substituting the value of E_g ($E_g = E_g^0 - 0.0591 \text{ pH}$)

$$E_{\text{cell}} = E_g^0 - 0.0591 \text{ pH} - E_{\text{calomel}}$$

$$\text{pH} = \frac{E_g^0 - E_{\text{cell}} - E_{\text{calomel}}}{0.0591}$$

Battery Technology:

Introduction

Battery is a device which transforms chemical energy into electric energy in which two or more electrochemical cells are connected in series or parallel and can act as a portable Source of electrical energy. Battery design is different for different applications. The size of the battery ranges from few millimeters to huge power house.

Batteries are used to power all electronic devices like calculators, watches, hearing aids, Computers. Batteries also find applications in emergency lighting in hospitals, UPS, electroplating, military and space vehicles.

Principal components of a battery

The principal components of a battery are,

- i. **Anode (Negative electrode):** Oxidation takes place by pumping the electrons to the external circuit. A good anodic material should possess the characteristics such as low reduction potential, good conductivity.
- ii. **Cathode (Positive electrode):** Reduction of active species takes place by accepting the electrons from the external circuit. A good cathodic material should possess the characteristics such as high reduction potential and stability in contact with the electrolyte.
- iii. **Electrolyte** (an ionic conductor): It is usually a solution of acids or alkalis or salts of high ionic conductivity. The electrolyte should be safe to handle and non-reactive with electrode material.
- iv. **Separator:** It separates anode and cathode compartments but allows the transformation of ions from anode to cathode and vice versa. The good separator should possess the characteristics such as, good strength, non-reactivity with active materials and good insulation property.
Ex; Polyolefins, cellulose, vinyl polymers etc.

Classification of Batteries:

Batteries are broadly classified into three types

1) Primary batteries (irreversible), 2) Secondary batteries (Reversible) and 3) Reserve batteries

- 1) **Primary batteries:** In these the cell reaction is not completely reversible. These are not rechargeable batteries and once discharged have no further electrical use.
Ex- dry cell (Leclanche cell, Zn-MnO_2)
- 2) **Secondary batteries:** The cell reaction occurring in secondary batteries are reversible and these are rechargeable.
Ex: Lead acid battery, Nickel - cadmium battery etc.
- 3) **Reserve batteries:** These are special purpose primary batteries designed for emergency and long term applications. The electrolyte is usually stored separately from electrodes to avoid deterioration of the active materials. The activation is done by adding to the cell components. Reserve batteries are primaries used to deliver high power for relatively short period of time used in missiles, mid ocean disasters
Ex- $\text{Zn-Ag}_2\text{O}$ batteries, Mg-water activated batteries
Reserve batteries have the following advantages
 - i) Unlimited shelf life
 - ii) High reliability of performance
 - iii) Variety of design options.

Battery Characteristics

The characteristics of a battery determine its suitability for the desired application. Certain important characteristics of a battery for commercial applications are listed below.

1. Cell Potential or Voltage: The voltage available from a battery depends on EMF of the cell, which is given by Nernst equation.

$$E_{\text{cell}} = E_{\text{cell}}^{\circ} - \frac{2.303 RT}{nF} \log Q$$

Where, $E_{\text{cell}}^{\circ} = E_{\text{cathode}}^{\circ} - E_{\text{anode}}^{\circ}$

and 'Q' is reaction quotient which is the ratio of [products]/[reactants]

The voltage of a cell depends on standard electrode potential of anode and cathode, temperature and Q.

- If the difference in standard electrode potential is more, higher is the voltage.
- As Q increases the voltage of the cell decrease.
- As the temperature increase the voltage of the cell marginally decreases.

OR

$$E_{\text{cell}} = E_c - E_a - |\eta_a| - |\eta_c| - iR_{\text{cell}}$$

where E_c and E_a are electrode potential of cathode and anode, $|\eta_a|$ and $|\eta_c|$ are over potentials at anode and cathode and iR_{cell} is internal resistance.

To obtain maximum voltage from the battery,

- The difference in the electrode potentials must be high.
- The electrode reactions must be fast so as to minimize the over potential.
- The internal resistance of the cell must be low, which can be achieved by using the electrolyte of higher conductivity.

2. Current: It is a measure of the rate at which battery is discharging. It is measured in ampere (A) and it is the amount of charge flowing per second. High current can be delivered if there is rapid electron transfer reaction.

3. Capacity: The capacity is the charge in ampere hours (Ah) that could be obtained from a battery during its discharge

It depends on size of battery and is given by Faraday relation.

$$C = \frac{mnF}{M}$$

Where m = mass of active material.

M = Molar mass of active material.

n = number of electrons involved in the cell

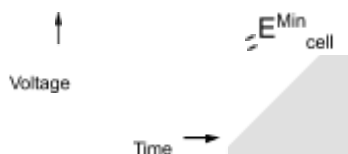
The capacity of the battery is determined by the amount of active materials actually consumed during the discharge.

The capacity is also dependent on discharge conditions. It is determined by finding for a fixed current discharge, the time taken for a battery to reach a minimum voltage E_{min} .

A plot of voltage against time at a fixed current discharge is as shown in the figure. The length of the flat portion of the curve indicates the capacity of the battery. The longer the flat portion of the curve, the better is the capacity of the battery.

Fig.





4. Electricity storage density: It is a measure of the charge per unit mass stored in the battery. Mass of the battery includes masses of electrolyte, current collectors, terminals, the case and other subsidiary elements. To get high electricity storage density the mass of subsidiary elements should be minimum.

5. Energy Efficiency: It is defined as the ratio of useful energy out put to the total energy in put. The energy efficiency of a secondary battery is given by.

$$\% \text{ energy efficiency} = \frac{\text{Energy released on discharge} \times 100}{\text{Energy required for charge}}$$

Higher the energy efficiency, better is the battery.

6. Cycle Life: Primary batteries are designed for single discharge but a secondary battery is rechargeable. The cycle life is the number of charge/ discharge cycles that are possible before failure occurs. The cycle life of a storage battery must be high.

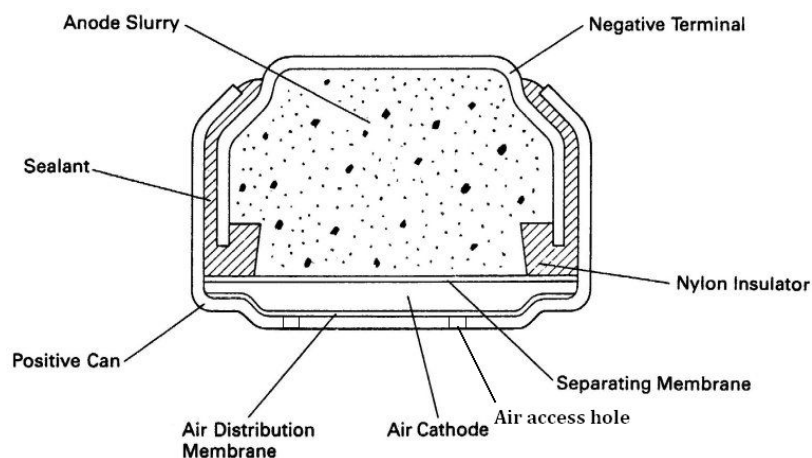
7. Shelf Life: The duration/ time of storage under specified conditions at the end of which the cell has the ability to deliver specified performance. A good battery should possess a long shelf life.

Zinc – Air Battery

Zinc-air battery is an example metal-air batteries. The Zinc-air cell consists of an anode can containing a mixture of zinc powder, 5M KOH solution as electrolyte and a gelling agent. The cathode is a nickel plated steel mesh coated with carbon/catalyst mixture and water repellents.

The cathode is laminated with a layer of Teflon containing air access holes. These holes provide path for oxygen to enter the cell and diffuse to cathode catalyst site. Plastic gasket is provided as insulation between two electrodes.

Fig.



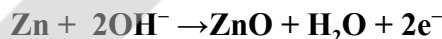
The cell is represented as,



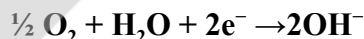
When battery is vented to the atmosphere, air enters the cell through air access holes, zinc gets oxidized to ZnO at the anode, during discharge. The oxygen of the air reacts with water at the cathode.

Electrode reactions –

At the anode.



At the cathode,



Net cell reaction is $\text{Zn} + \frac{1}{2} \text{O}_2 \rightarrow \text{ZnO}$

The cell produces an open circuit potential of **1.4 V**.

It has high capacity, high energy density (100 Wh kg⁻¹), long Shelf life, Low operating cost and it is environmentally safe.

Hygroscopic materials in the battery and limited power output are the limitations of this battery.

Applications -

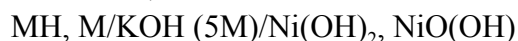
- 1) These cells are widely used in hearing aids, telecommunication devices such as pagers and wireless head sets,
- 2) Used in various medical devices, such as patient monitors and recorders, drug infusion pumps
- 3) Used in rail road signaling, seismic telemetry, remote communications etc.

Nickel- Metal Hydride batteries

Nickel metal hydride batteries are similar to Ni-Cd batteries but are eco-friendly and have high capacity. The cathode is a highly porous sintered nickel substrate into which nickel oxyhydroxide is pasted. The anode is a highly porous with a nickel wire gauge grid into which the active hydrogen storage metal alloy is coated. Most of the Ni-MH cells use AB₅ (Ex: LaNi₅, CeNi₅) or AB₂ (Ex: TiNi₂, VN_{i2}) type metal alloys.

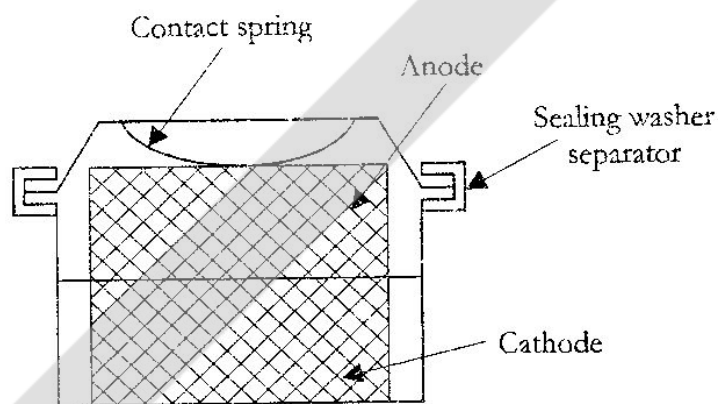
The electrodes are separated with a synthetic non woven material serves as separator between electrodes. KOH is used as electrolyte.

The battery may be represented as,



A button type cell is shown in the figure

Fig.



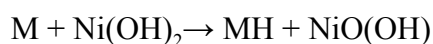
Electrode Reactions – During discharge,

At the anode, $\text{MH} + \text{OH}^- \rightarrow \text{M} + \text{H}_2\text{O} + \text{e}^-$

At the cathode, $\text{NiO(OH)} + \text{H}_2\text{O} + \text{e}^- \rightarrow \text{Ni(OH)}_2 + \text{OH}^-$

The net cell reaction is, $\text{MH} + \text{NiO(OH)} \rightarrow \text{M} + \text{Ni(OH)}_2$

During charging, the above reaction is reversed.



The open circuit potential of cell is 1.35 V.

The cell has high capacity, long cycle life, long shelf, no environmental problems, No Maintenance required.

Applications :

In Cellular Phones, emergency back up lighting, laptops, in electric vehicles (These have been developed on a commercial basis by the Ovonic Battery company, USA essentially for electrically run automobiles.)

Lithium Batteries

In 1990's battery industry was revolutionized by the invention of use of lithium as an anodic material, because of its light weight, low electrode potential (-3.05 V), high electrochemical equivalence (3.86 Ahg^{-1}) and good electrical conductivity. Lithium batteries offer voltages up to 4 V compared with 1.5 V offered by other primary batteries.

The electrolytes used in lithium batteries cannot be aqueous solution because of high reactivity of Li with water organic solvent like either, acetonitrile, THF or molten salt Eg – LiCl + KCl are used electrolyte.

Advantages :

- 1) High Cell Voltage (Above 4V)
- 2) High energy density.
- 3) Operation over wide range of temp 70°C.
- 4) Superior Shelf Life.
- 5) Produces constant voltage.

Lithium Ion Batteries

A lithium-ion battery (sometimes Li-ion battery or LIB) is a member of a family of rechargeable battery types in which lithium ions move from the anode to the cathode during discharge and back when charging.

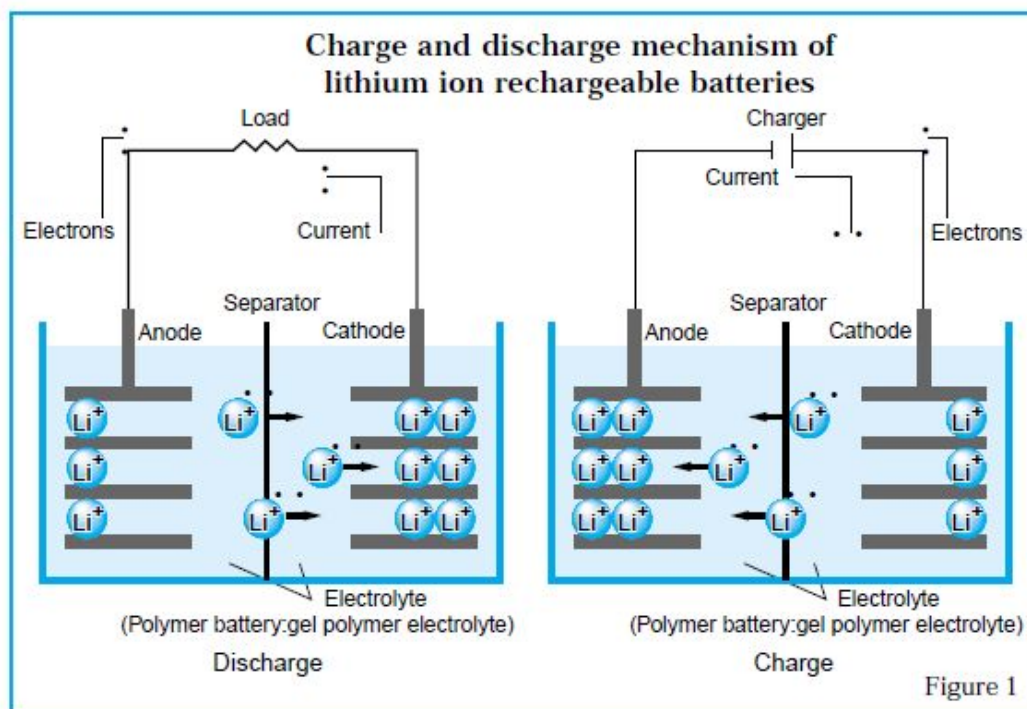
Construction:

Lithium-ion battery consists of an Anode made of layered carbon or graphite and a Cathode made up of intercalated lithium metal oxide such as lithium cobalt oxide (LiCoO_2). The electrolyte used is a lithium salt such as lithium hexafluorophosphate (LiPF_6), in an organic solvent like ethylene carbonate or diethyl carbonate. Micro porous polyethylene or polypropylene separator is used.

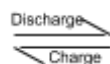
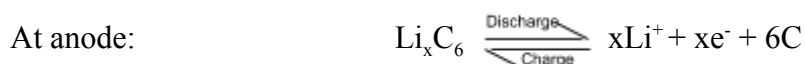
Charge/discharge mechanism:

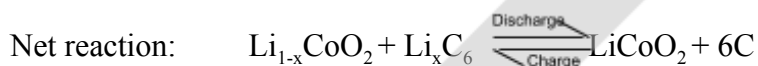
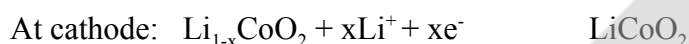
Unlike other batteries lithium ion batteries require charging before they are put to use. Battery charging and discharging occur through the migration of lithium ions between the cathodes and anodes through doping and de-doping.

More specifically, during charging lithium is de-doped from cathode LiCoO_2 , and it is doped in inter layers of carbon in anode. During discharge lithium is de-doped from the carbon layers at anode and doped in the cathode. Doping and de-doping mechanisms are shown in the Figure.



The chemical reactions for charge and discharge are as shown below:





Advantages:

High voltage: Lithium ion batteries produce 3.7 volts, approximately three times the voltage of Ni-MH batteries or Ni-Cd batteries. This will make it possible to have smaller, lighter equipment.

High energy density: Because the lithium ion batteries are high voltage/light weight batteries, they boast a higher energy density than Ni-MH batteries or Ni-Cd batteries.

Wide range of operating temperature: -40°C to $+60^\circ\text{C}$

Flat Discharge Voltage: Production of stable power throughout the discharge period of the battery.

Applications: Mobile phones and smart phones, laptops and tablets, digital camera, camcorders, electric vehicles, electric wheelchairs etc.

Fuel Cells

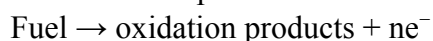
The first fuel cell was discovered by a British judge, Sir William Grove. The research on fuel cell's got importance as the convention energy sources are depleting and also for reduction of emission of green house gases. The fuel cells are expected to play a vital role in the future energy scenario, particularly, when hydrogen is projected as the main energy source of the 21st century. The fuel cells are used as auxiliary power generators in space vehicles.

Fuel cell is a galvanic cell in which the chemical energy contained in a readily available fuel oxidant system is converted directly into electrical energy by means of electro chemical processes.

A fuel cell essentially consists of the following arrangement

fuel / electrode / electrolyte / electrode/ oxidant

At the anode, oxidation of fuel takes place



At the cathode, reduction of oxidant takes place



Differences between a battery and a fuel cell

Sl. No.	Battery	Fuel Cell
1.	Batteries store chemical energy	Fuel cells do not store chemical energy
2.	Reactants are stored in the cell	Reactants are supplied from outside the cell
3.	The electricity is generated till the active materials in the cell exhaust	The electricity is generated as long as fuel and oxidants are supplied from outside
4.	Batteries usually contain toxic substances like Pb, Cd, etc.	They are eco-friendly since no toxic chemicals are produced

Advantages:

- 1) The efficiency energy conversion is high.
- 2) No moving parts and so elimination of wear and tear.
- 3) Silent operation.
- 4) No harmful products are produced.
- 5) No need of charging.

Limitations:

- 1) Fuel in the form of gases and oxygen need to be stored in tanks under high pressure.
- 2) Power output is moderate.

Classification of Fuel cells based on the electrolyte used:

Types	Electrolyte used	Operating temperature
Alkaline fuel cell [AFC]	Aq. KOH solution	60-120 °C
Polymer electrolyte membrane fuel cell [PEMFC]	Polymer membrane (Nafion)	60-120 °C
Molten carbonate fuel cell [MCFC]	Alkali carbonates (LiCO_3 or K_2CO_3)	600-650 °C
Phosphoric acid fuel cell [PAFC]	Concentrated phosphoric acid	180-220 °C
Solid oxide fuel cell [SOFC]	Ceramic solids such as ZrO_2 or Y_2O_3	900-1000 °C

Polymer electrolyte membrane fuel Cell (Proton exchange membrane fuel cell)

The polymer electrolyte membrane fuel cell (PEMFC) consists of porous carbon coated with platinum catalyst as anode and cathode electrodes. Water-based, acidic polymer membrane (Nafion membrane) electrolyte is sandwiched between two electrodes. At anode hydrogen is used as fuel and at cathode oxygen is used as oxidant. PEMFC cells operate at relatively low temperatures (below 100 degrees Celsius). The electrolyte allows only hydrogen ions to pass through it and not either electrons or hydrogen gas.

Hydrogen fuel is supplied at the anode, where oxidation of hydrogen takes place and the electrons are liberated. H^+ ions pass through the electrolyte membrane towards the cathode and electrons are moved to external circuit. On the other hand at cathode, oxygen is passed which undergoes reduction with the formation of water.

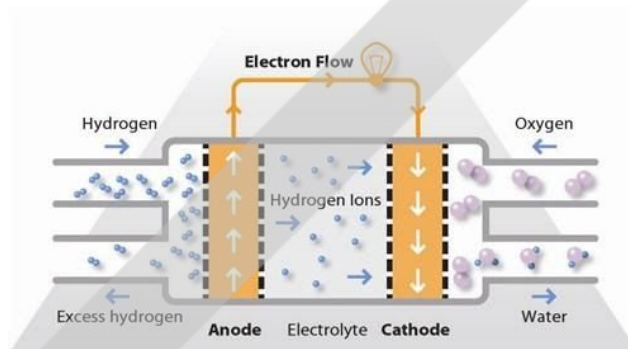
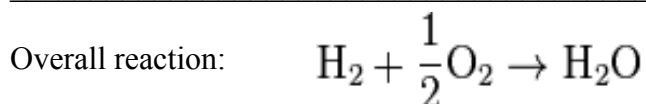
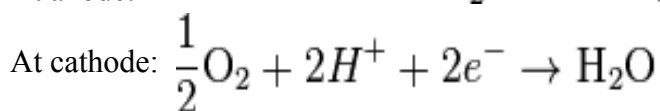


Diagram of a PEM fuel cell

Reactions:



Applications:

1. PEMFCs are most suited for transportation applications.
2. Due to their fast startup time and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

Photovoltaic Cells or Solar cells

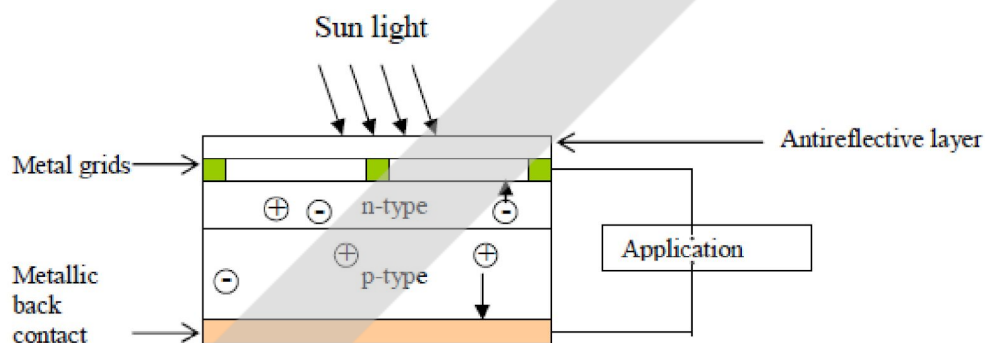
Introduction

With increase in population, the energy requirement is also increasing. The increased demand for energy is not easily met by non-renewable sources. As the reserves of fossil fuels are very limited and are being depleted very fast, search for alternate sources of energy has gained a lot of importance. The world is looking towards natural resources such as solar energy, wind energy, bio-energy, geothermal energy etc. Out of these, solar energy is one of the important sources of energy. An important aspect of solar energy is that, it is non-depleting, non-polluting and available freely.

“Photovoltaic cells or solar cells are often referred to as semiconductor device that converts sunlight into direct current electricity”. As long as light is shining on the solar cell, it generates electrical power. When light stops, electricity stops. Solar cells never need recharging like battery.

Power generation from solar PV has long been seen as a clean sustainable energy technology which draws upon the planet's most plentiful and widely distributed renewable energy source - the sun.

Construction and working of PV cells



Construction: Silicon photovoltaic cell is composed of a thin wafer (250 to 300 μm) consisting of an ultra thin layer of phosphorous doped (n-type) silicon on top of the boron doped (p-type) silicon. Hence, a p-n junction is formed between the two. A metallic grid forms one of the electrical contacts of the diode and allows light to fall on the semiconductor between the grid lines. An antireflective layer (TiO_2 or SiN) between the grid lines increases the amount of light transmitted to the semiconductor. The cell's other electrical contact is formed by a metallic layer on the back of the solar cell.

Working: When light radiation falls on the p-n junction diode, electron hole pairs are generated by the absorption of the radiation. The electrons are drifted to and collected at the n-type end and the holes are drifted to and collected at the p-type end. A strong electric barrier exists at the depletion region. When these two ends are electrically connected through a conductor there is a flow of current between the two ends through the external circuit. Thus photoelectric current is produced and available for use.

The current output of a cell depends on its size and efficiency, which is proportional to the intensity of solar radiation striking on the surface of the cell. Photovoltaic cells are connected in series or parallel circuits to produce higher voltages.

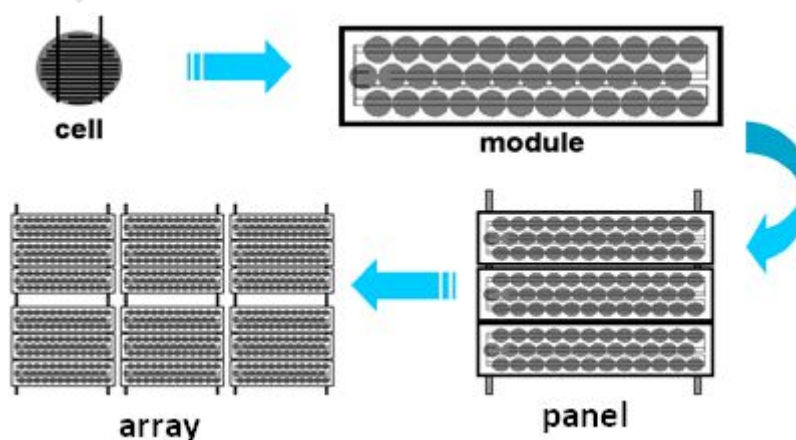
Advantages of photovoltaic cells

1. Photovoltaic's is considered to be the future sustainable energy system, which is unlimited and renewable.
2. Photovoltaic cells provide power for space craft and satellites.
3. Developments in the field photovoltaic cell will boost the semiconductor industry.
4. Photovoltaic energy conversion is highly modular. Power supply to remote areas where the grid extension is economically not feasible.
5. Low operating cost.
6. No moving parts and no wear and tear
7. Quick installation.
8. No emissions, no combustion residues for disposal, which does not contribute to global warming.
9. Excellent safety record and public acceptance is high.

Photovoltaic cells, modules, panels and arrays

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. *Photovoltaic modules* consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems. *Photovoltaic panels* include one or more PV modules assembled as a pre-wired, field-installable unit. A *photovoltaic array* is the complete power-generating unit, consisting of any number of PV modules and panels.

The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 25°C (77°F), and incident solar irradiance level of 1000 W/m² and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating.

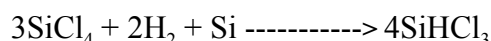


Production of solar grade silicon by Union carbide process

In the Union Carbide process metallurgical grade silicon with 98.5% purity is used to produce solar grade silicon

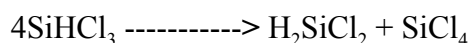
Process is as below:

The hydrogenation of tetrachlorosilane through a bed of metallurgical silicon is carried out in a fluidized bed reactor.



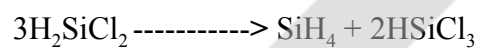
The trichlorosilane is separated by distillation while the unreacted tetrachlorosilane is recycled back to the hydrogenation reactor.

The purified trichlorosilane is passed through a fixed bed column filled with quaternary ammonium ion exchange resin acting as catalyst. Trichlorosilane gets converted into dichlorosilane.



The products are separated by distillation, tetrachlorosilane is recycled to the hydrogenation reactor and dichlorosilane is passed through a second fixed bed column filled with quaternary ammonium ion exchange resin. Dichlorosilane is converted into silane.

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Department of Chemistry



The above products are separated by distillation and trichlorosilane is recycled to the first fixed bed column. Silane is further purified by distillation and then pyrolyzed to produce polysilicon onto heated silicon seed rods mounted in a metal bell-jar reactor.