1.a. Answer:

The device, which converts solar energy into electrical energy, is called photovoltaic cell and the phenomenon is called photovoltaic effect.

Construction:

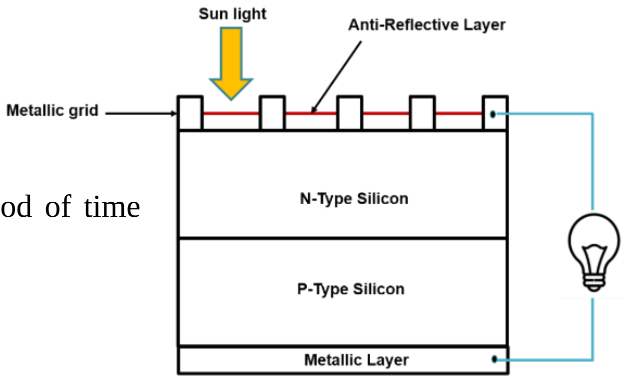
- Photovoltaic Cells consists of p-n junction semiconductor diode made of silicon coated with anti-reflective layer (TiO_2) at the top.
- Two electrical contacts are provided, one in the form of metallic grid at the top of the junction and the other is a silver layer at the bottom of the cell
- The antireflective layer coated in between the metallic grids which allow light to fall on the semiconductor.

Working of photovoltaic cell:

- Electromagnetic radiation consists of particles called photons (hv). They carry a certain amount of energy given by the Plank quantum equation. $E = hc/\lambda$

Where, h = Planck's constant, c = velocity of light, λ = wavelength of the radiation

- The photons of solar radiations enter **n-type** semiconductor breaks barrier potential and moves to **p-type** semiconductor where photons knock the electrons in p-type to form electron-hole pair.
- The free electrons so formed will travels through the circuit from **n-type** and recombines with holes again in the **p-type** region.
- The movement of electrons from n-type to p-type generates electric current. The electrical energy produced by the solar cell is used for various applications



Advantages of PV cells:

- It is unlimited, inexhaustible and renewable source of energy.
- The solar cell operates reliably for a long period of time with no maintenance.
- Easy to operate

Disadvantages of PV cells:

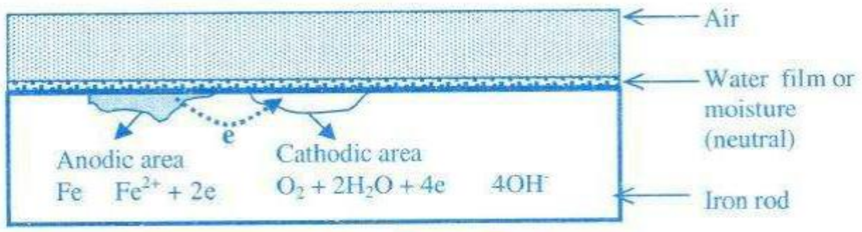
- High installation cost.
- Energy can be produced only during the day-time.

- The efficiency of solar cells depends on climate.

1.b. Answer:

Destruction of metal surface in surrounding environment due to chemical or electrochemical reaction is known as corrosion. E.g., rusting of iron.

Electrochemical theory of corrosion:



(i) According to electrochemical theory, corrosion of metals takes place due to the formation of minute galvanic cells over the surface of metal. Thus anodic and cathodic regions are formed on the same metal surface or when two metals are in contact with each other in the presence of a conducting medium.

(ii) At the anodic region oxidation reaction takes place and the metal gets converted into its ions by liberating electrons. Consequently, metal undergoes corrosion at the anodic region.

$$\mathbf{Fe \longrightarrow Fe^{2+} + 2e^-}$$

(iii) The electrons flow from the anodic to cathodic area and at the cathodic region, reduction takes place. Since metal cannot be reduced further, metal atoms at the cathodic region are unaffected by the cathodic reaction. Some constitutions of the corrosion medium take part in the cathodic reaction. There are three possible ways in which the reduction can take place.

- <u>If the solution is aerated and almost neutral,</u>
    - $\mathbf{O_2 + H_2O + 2e^- \longrightarrow 2OH^-}$
- <u>If the solution is deaerated and almost neutral:</u>

$$\mathbf{2H_2O + 2e^- \longrightarrow H_2 + 2OH^-}$$

- <u>If the solution is deaerated and acidic:</u>

$$\mathbf{2H^+ + 2e^- \longrightarrow H_2 \uparrow}$$

(iv) Corrosion of iron produced Fe 2+ ions and OH- ions at the anode and cathode sites respectively. These ions diffuse towards each other and produce insoluble Fe (OH)$_2$.

$$Fe^{2+} + 2\,OH^- \longrightarrow \underset{\text{(Ferrous hydroxide)}}{Fe(OH)_2}$$

(v) In an oxidizing environment, it is oxidized to ferric oxide and the rust is hydrated ferric oxide.

$$2Fe(OH)_2 + 1/2O_2 + H_2O \longrightarrow [Fe_2O_3.3H_2O]\ [Rust]$$

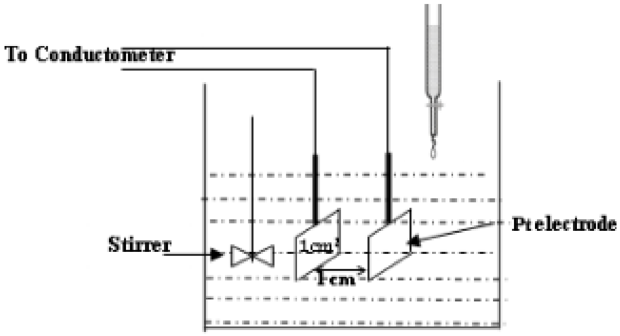
2. a Answer:

Theory: Conductometry is based on Ohm’s law which states that the current i (amperes) flowing in a conductor is directly proportional to the applied electromotive force, E (volts), and inversely proportional to the resistance R (ohms) of the conductor.

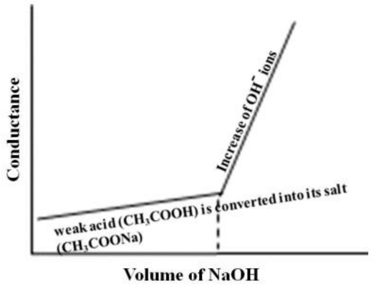
$$i = E/R$$

The reciprocal of the resistance is called the conductance (Ease with which electric current flows through a conductor). Specific conductance of a solution is defined as the conductance of a solution present between two parallel electrodes which have 1cm^2 area of cross section and which have kept 1 cm apart. The conductance of solution depends on the number and mobility of ions. The substitution of ions with different ionic mobility affects the electrolytic conductivity. Therefore, the equivalence point can be determined by means of conductivity measurement for a neutralization reaction between an acid and a base. Equivalence point is determined graphically by plotting conductance against titer values.

Instrumentation: Conductometer consists of: (1) conductivity cell having two platinum electrodes; and a (ii) conductometer. A simple arrangement of conductometric titration is depicted in figure. The solution to be titrated is taken in the beaker.



Application: (i) used to check water pollution in lakes as well as rivers. (ii) used to check the alkalinity of the fresh water (iii) Purity of distilled water and deionized water can determined.



Pipette out 50 ml of sample (weak acid) into a beaker. Immerse the conductivity cell into it. Connect the conductivity cell to a conductivity meter and measure the conductance by adding NaOH from the burette by increment of 1 ml. Plot a graph of conductance against volume of NaOH. Determine the neutralization point from the graph as shown below.

2.b Answer:

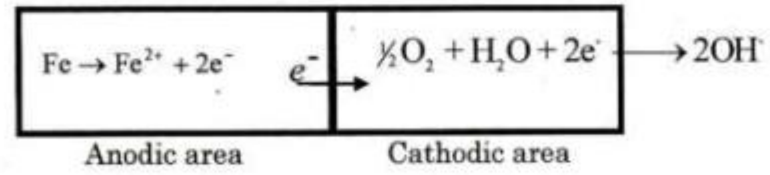
Corrosion Penetration Rate (CPR) is defined in three ways: (1) the speed at which any metal in a specific environment deteriorates due to a chemical reaction in the metal when it is exposed to a corrosive environment, (2) the amount of corrosion lost per year in thickness, (3) the speed at which corrosion spreads to the inner portions of a material.

Corrosion penetrating rate in mpy	Corrosion penetrating rate in mm/y
CPR = KW/DAT	CPR = KW/DAT
Weight loss, W= 585 × 10^3 mg	Weight loss, W= 585 × 10^3 mg
Density, D = 7.9 g/cm^3; Time, T = 3×24×365	Density, D = 7.9 g/cm^3; Time, T = 3×24×365
Area A = 540/6.45 = 83.72 $inch^2$	Area A = 540 cm^2
CPR = $\frac{534\times 585 \times 10^3}{7.9 \times 83.72 \times 3 \text{ x } 24\times365}$	CPR = $\frac{87.6 \times 585 \times 10^3}{7.9 \times 540 \times 3 \text{ x } 24\times365}$
CPR = 17.97 mpy	CPR = 0.457 mm/y

3.a. Answer:

(i) Type of corrosion is **"Differential metal corrosion",** this occurs when two dissimilar metals are in contact with each other in a corrosive conductive medium; a potential difference is set up resulting in a galvanic current. The metal with lower electrode potential or more active metal acts as anode and the metal with higher electrode potential acts as cathode. The anodic metal undergoes corrosion whereas cathodic metal gets unattacked. In the given example steel act as a anode and tin act as a cathode and its reaction are as follows,

At the anode $Fe \rightarrow Fe^{2+} + 2e^-$
At the cathode $H_2O + ½ O_2 + 2e^- \rightarrow 2OH^-$



(ii) Type of corrosion is **"Differential aeration corrosion",** this take place due to the formation of different oxygen concentration. The part of metal exposed to ***lower concentration*** of oxygen (dissolved oxygen) acts as anodic area and undergoes corrosion. The part of the metal above the water level is exposed to ***higher concentration*** of oxygen acts as cathodic are and remains unaffected. A ***distinct brown line*** is formed just below the ***water line*** due to the deposition of rust. Water line corrosion is observed usually in steel water tanks and ships floating in sea water for a long time.

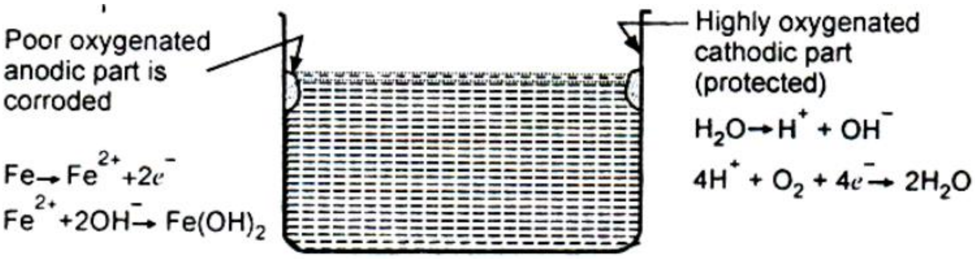
Cell Reaction:

At the anode (less O_2 concentration): $Fe \rightarrow Fe^{2+} + 2e^-$

At the cathode (more O_2 concentration): $O_2 + 2\,H_2O + 4e^- \rightarrow 4\,OH^-$

$$Fe^{2+} + 2OH^- \rightarrow Fe\,(OH)_2$$

$$2Fe(OH)_2 + 1/2O_2 + H_2O \rightarrow [Fe_2O_3.\ 3H_2O]\ \text{(rust)}$$

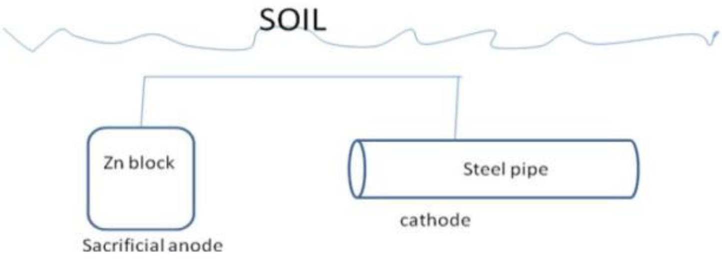


3.b Answer:

Cathodic protection is a method of protecting a metal or alloy from corrosion by converting it completely into cathodic and no part of it is allowed to act as anode.

Sacrificial anodic protection:

- The base metal is usually iron, copper or brass.
- The metal to be protected from corrosion is converted into cathode by connecting to a metal which is anodic to it.
- Metals like Mg, Al and Zn are more active and hence are used as anodes.
- Since the anodic metals are sacrificed to protect the metal structure, the method is known as sacrificial anode method.
- These metals being more active acts as anode undergo corrosion and supply electrons to the target metal.
- In this way the protected metals acts as cathode.



4.a Answer:

The electrodes whose potentials is known and constant and they are used to determine the potential of another unknown electrode are known as reference electrodes.

Construction and working of calomel electrodes:

- The calomel electrode consists of two glass tube.
- At the inside glass tube, there is a paste (calomel) of mercury and mercurous chloride (Hg_2Cl_2) at the bottom of a narrow glass tube.
- Pure mercury is filled below the paste and connected with platinum wire for external electrical contact
- This narrow tube placed inside an outer glass tube filled with a saturated KCl solution.

Cell representation: $Hg(s)/Hg_2Cl_2$ (paste);Cl-

If the electrode behaves as anode, the electrode reaction is:

$$2Hg_{(l)} \rightarrow Hg_2^{+2} + 2e^-$$

$$Hg_2^{+2} + 2Cl^- \rightarrow Hg_2Cl_{2(s)}$$

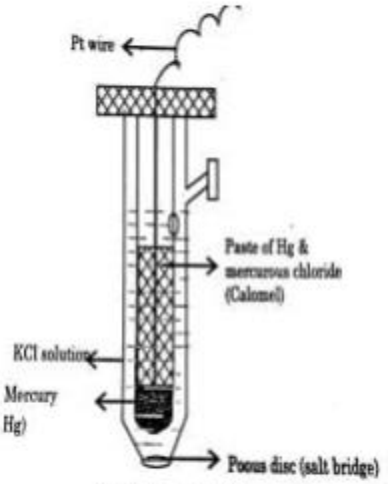
$$2Hg_{(l)} + 2Cl^- \rightarrow Hg_2Cl_{2(s)} + 2e^-$$

If the electrode behaves as cathode, the electrode reaction is:

$$Hg_2^{+2} + 2e^- \rightarrow 2Hg_{(l)}$$

$$Hg_2Cl_{2(s)} \rightarrow Hg_2^{+2} + 2Cl^-$$

$$Hg_2Cl_{2(s)} + 2e^- \rightarrow 2Hg_{(l)} + 2Cl^-$$



Calomel electrode

The electrode potential of calomel electrode depends on concentration of chloride ions. For saturated KCl E=0.2422V (called Saturated calomel electrode)

4.b Answer:

Cell representation: Ag/Ag+ (x) // Ag+ (0.43 M)/Ag

Cell reaction:

Anode: $Ag \rightarrow Ag^+$ (0.005 M) + e^-

Cathode : Ag^+ (x M) + $e^- \rightarrow$ Ag

Under the given condition (T=25℃)

E_{cell} = 0.0591/n log [C_2/C_1]

Where C_2 = Concentration of electrolyte at cathodic compartment = x M

C_1 = Concentration of electrolyte at anodic compartment = 0.005 M
n = 1

Substituting the above values in above formula,

0.195 = 0.0591/1 [log x/0.005]

0.195 = 0.0591 [log x – log (0.005)]

0.195 / 0.0591 = log (x) + 2.3

3.2995 – 2.3 = log (x)

x = Antilog (0.9995)

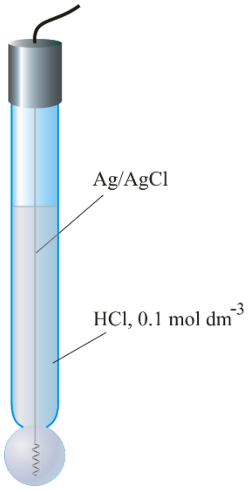
x = 9.95 M

5.a Answer:

The ion-selective electrode generally consists of a membrane that selectively responds to a specific ion in a mixture of ions in solutions that ignore all other ions and develop a potential.

Construction:

- The glass electrode consists of a glass tube made up of a special type of glass with high electrical conductivity.
- The glass tube contain a solution of concentration C1 (0.1M HCl)
- An Ag-AgCl electrode is placed inside the solution which acts as internal reference electrode and also serves for the external electrical contact.
- The glass electrode is dipped in unknown solution of concentration C2.



Cell representation

Ag / AgCl /HCl (0.1M) / unknown solution / Glass

Working: The glass electrode is dipped into any solution containing H^+ ions then glass electrode develops potential called as glass electrode potential. It is represented as EG.

Then, $EG = E_b + E_{Ag/AgCl} + E_{assy}$ .... (1)

Where, E_b= Boundary potential, $E_{Ag/AgCl}$ = Potential due to Ag/AgCl and E_{assy}= asymmetric potential.

Boundary potential (Eb); It is a potential developed across the glass membrane when concentration of the solution inside and outside the glass membrane are different.

Mathematically it is represented as, $\mathbf{E_b = E_1 - E_2}$

Where, E_1= Potential due to H^+ present inside the bulb (Unknown solution)

E_2 = Potential due to H^+ present in outside solution (Unknown solution)

According to Nernst equation

$$= E^\circ + \frac{0.0591}{n} \log C_2 - \left(E^\circ - \frac{0.0591}{n} \log C_1\right)$$

$$= \frac{0.0591}{n} \log C_2 - \frac{0.0591}{n} \log C_1$$

Where, $C_1 = 0.1$ M and $n = 1$ (H^+)

$$= \frac{0.0591}{n} \log C_2 - \mathbf{K} \quad \textbf{or}$$

$$= \mathbf{K} + \frac{0.0591}{n} \log C_2$$

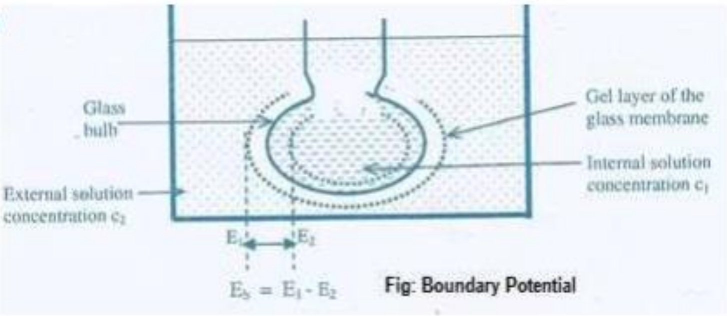


Fig: Boundary Potential

Glass selects only H^+ ions ignoring other ions.

Hence $C_2 = H^+$

$E_b = K + 0.0591 \log [H^+]$, Where, $\log [H^+] = -pH$

Hence $E_b = K - 0.0591pH$ ---------------------(2)

Substituting eqn (2) in (1)

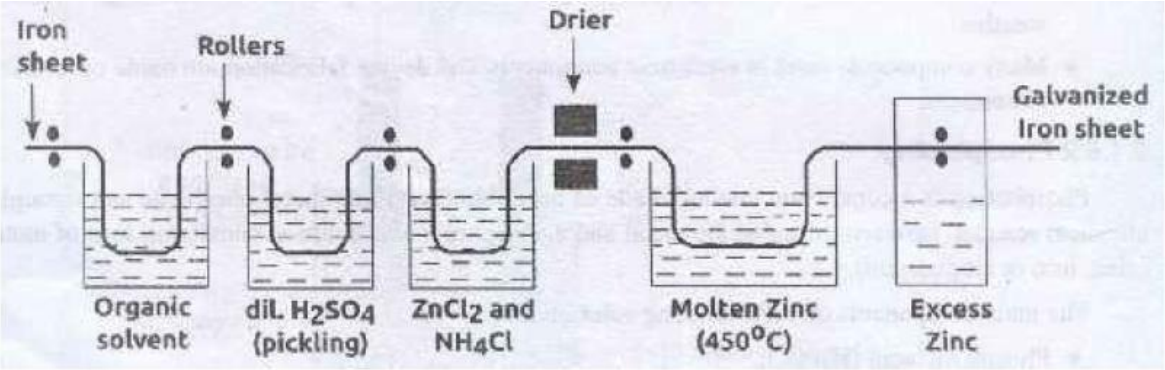
$E_G = K - 0.0591\ pH + E_{Ag/AgCl} + E_{assy}$

$E_G = E^o_G - 0.0591\ pH$

It is used to determine the pH of the unknown solution along with calomel electrode.

5.b. Answer:

Galvanisation is a process of coating a base metal surface with Zinc metal. Galvanisation is carried out by hot dipping method.



The galvanization process involves the following steps.

1. The metal surface is washed with organic solvents to remove organic matter on the surface.
2. Rust and other deposits are removed by washing with dilute sulphuric acid.
3. Finally the article is well washed with water and air-dried.
4. The article is then dipped in a bath of molten zinc, maintained at 425 – 430°C and covered with a flux of ammonium chloride to prevent the oxidation of molten Zinc.
5. The excess Zinc on the surface is removed by passing through a pair of hot rollers, which wipes out excess of Zinc coating and produces a thin coating.

6.a Answer:

Working Principle

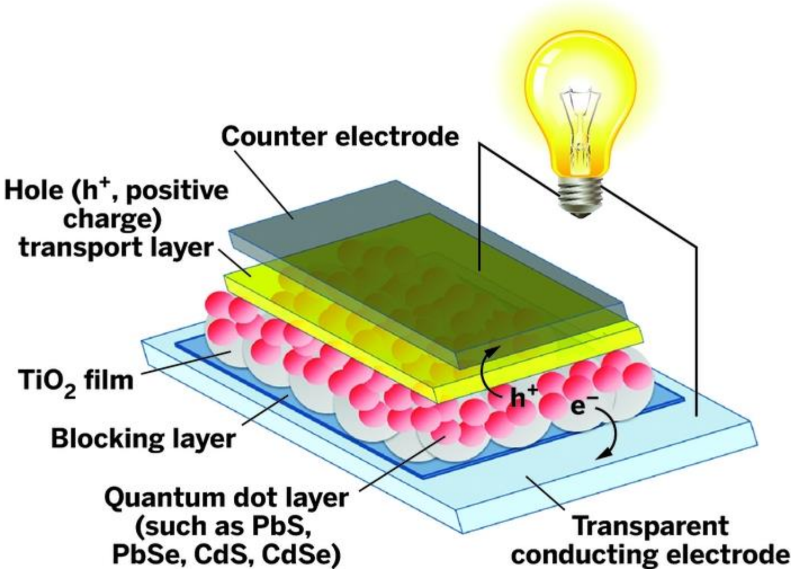
- When sunlight strikes the QDs, the absorbed photons excite electrons in the QDs to higher energy levels, creating electron-hole pairs.

  Excitation process: $QDs + h\nu \rightarrow QDs^*$

  Exciton dissociation: $QDs^* \rightarrow e^- + h^{+*}$ (free energy)
- The electrons and holes then separate due to the built-in electric field of the QDSC, and the electrons move towards the electron acceptor while the holes move towards the electrode.

  Injection process: $QDs^* + TiO_2 \rightarrow TiO_2e\text{-}^* + QDs^+$
- The electrons flowing through the electron acceptor are collected by the electrode and routed to an external circuit, generating a flow of electric current.

  Energy generation: $TiO_2e\text{-}^* + C.E \rightarrow TiO_2 + e^* (CE)$
- The holes, on the other hand, combine with the electrolyte or the hole acceptor material to complete the circuit.



Properties:

- **Light absorption**: QDs have a narrow and well-defined absorption spectrum, which allows for efficient light absorption over a wide range of wavelengths, including the near-infrared region.
- **Charge separation**: It can efficiently separate charges generated by absorbed light, increasing the overall efficiency of the solar cell.
- **Long carrier lifetime**: The long carrier lifetime of quantum dots allows for efficient collection of charges generated by absorbed light, increasing the overall efficiency of the solar cell.
- **High surface area**: Quantum dots have a high surface area, which allows for efficient loading of photosensitizers, increasing the overall efficiency of the solar cell.

Application:

- **Solar energy conversion**: QDSSCs make them suitable for use in solar energy conversion systems, such as photovoltaic panels and solar-powered devices.
- **Portable electronics**: QDSSCs are lightweight and flexible, making them suitable for use in portable electronic devices, such as smartphones, laptops, and wearable devices.
- **Building-integrated photovoltaics** (BIPV): QDSSCs can be integrated into building materials, such as windows, roofs, and walls, allowing for the conversion of light into electrical energy within a building.
- **Stand-alone power systems**: QDSSCs can be used in stand-alone power systems, such as remote solar-powered systems, to provide electrical power without the need for a grid connection.

6.b. Answer:

Number average molecular mass:

Total weight = (35 x 22000) + (45 x 20000) + (20 x 15000) = 770000 + 900000 + 300000 = 1970000

Total number = 35 + 45 + 20 = 100

$$M_n = \frac{\Sigma M_i N_i}{\Sigma N_i}$$

Mn = 1970000 / 100 = **19700 g/mol**

Weight average molecular mass:

$$M_W = \frac{\Sigma N_i (M_i)^2}{\Sigma N_i M_i}$$

$$\mathbf{M_w} = \frac{\{[35 \text{ x } (22000)^2] + [45 \text{ x } (20000)^2] + [20 \text{ x } (15000)^2]}{1970000}$$

M_w = 20020.30 g/mol

7.a Answer:

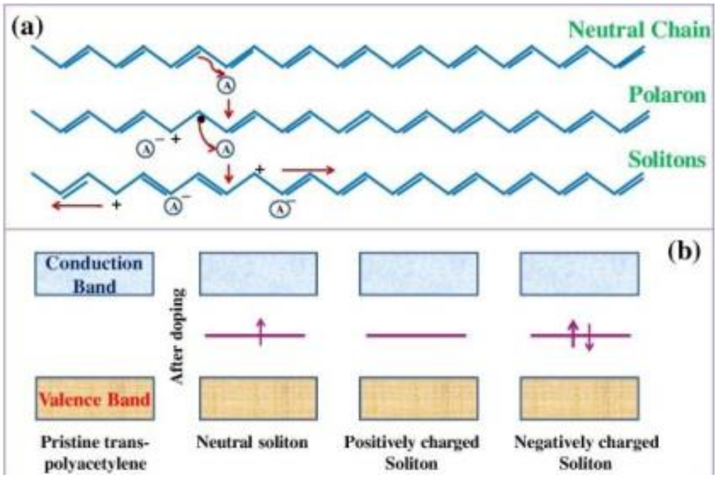
Mechanism of Conduction: (Oxidative doping (p-doping))

i. When the **oxidative dopant** such as iodine is added, it takes away an electrons from the π-back bone of the pollyacetylene chain and creates a positive centre (hole) on one of the carbon.

ii. The other π-electron resides on the other carbon making it a radical. The radical ion formed is called Polaron. A dipolar on (soliton) is formed on further oxidation.

iii. These radicals migrate and combine to establish a backbone double bond. As the two electrons are removed, the chain will have two positive centre (holes).

iv. The chain as a whole is neutral, but holes are mobile and when a potential is applied the migrate from one chain as a whole is neutral but holes are mobile and when a potential is applied they migrate from one carbon to another and account for conductivity. This depicted by the sequence of reaction.



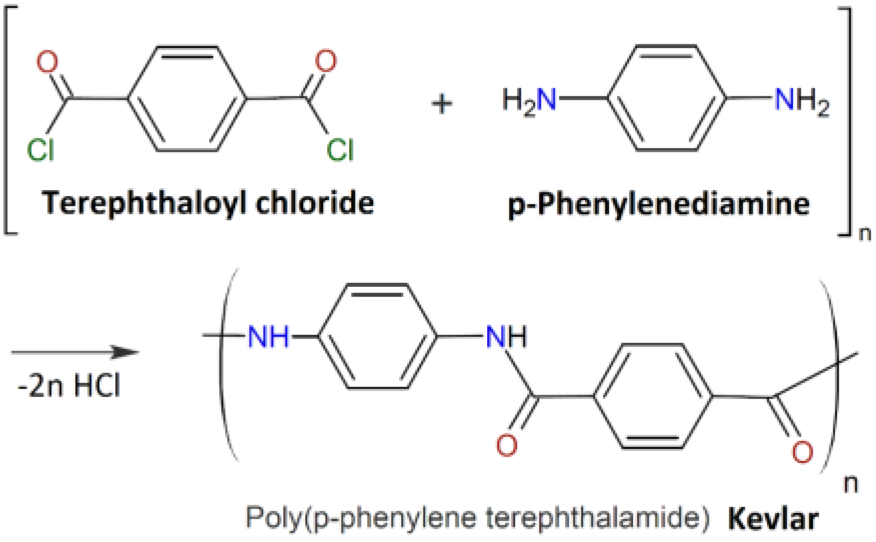
Application

- Non-volatile memory devices based on organic transistors.
- Fabrication of organic photovoltaic cells.
- Fabrication of organic light-emitting devices (OLED).
- Conducting polymer actuators and Micropumps.

7.b Answer:

Preparation of Kevlar

Kevlar is prepared by polycondensation between aromatic dichloride like terephthaloyl acid chloride and aromatic diamines like p-phenylenediamine.



Properties of Kevlar

1. It is exceptionally strong, 5 times stronger than steel and 10 times stronger than aluminium.
2. It is thermally stable up to 450°C.
3. It is also stable at very low temperatures (up to -196°C)
4. Kevlar can resist attacks from many different chemicals

Applications

1. Kevlar is widely used in the production of bulletproof vests, military helmets and body armour.
2. Kevlar is used in protective clothing for military personnel, law enforcement officers and firefighters.
3. Kevlar is used in various industrial applications, such as conveyor belts, hoses, and gaskets
4. Kevlar is employed in the aerospace and aviation industries for its lightweight properties and ability to withstand high temperatures.

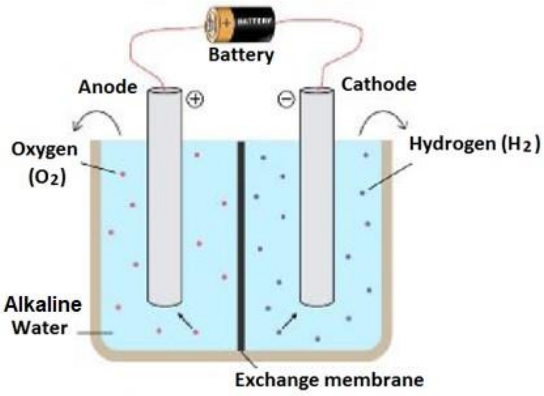
8.a Answer:

Green fuels are energy sources that can be used as substitutes for traditional fuels, such as diesel and natural gas. Due to lower carbon emissions green fuels are considered more environmentally friendly.

Example: Biodiesel, hydrogen gas, and solar power.

Alkaline Water Electrolysis

- It consists of two electrodes i.e. anode and cathode.
- Both electrodes are made up of Ni based metal, because it is more stable during the oxygen evolution.
- These electrodes are immersed in KOH solution (25-35%).
- Both electrodes are separated by porous diaphragm prevent gases crossover and allows only hydroxide ions.
- When electricity is passed, at anode hydroxide ions lose electrons and forms water molecules.
- At cathode, water molecules accept electrons and liberate hydrogen gas and forms hydroxide ions.



- These hydroxide ions move from cathode to anode through diaphragm and process continues.

  Anode Reaction (Oxidation process): $4\ OH^{-}\ (aq) \rightarrow O_2\ (g) + 2H_2O + 4\ e^{-}$

  Cathode Reaction (Reduction process): $4\ H_2O + 4\ e^{-} \rightarrow 2H_2\ (g) + 4\ OH^{-}\ (aq)$

  Overall cell reaction: $2H_2O\ (aq) \rightarrow 2H_2\ (g) + O_2\ (g)$

Advantages

- Well established technology
- Low cost technology
- The energy efficiency is 70–80%
- Commercialized

8.b Answer:

Battery is a device that converts chemical energy directly into electrical energy via electrochemical oxidation and reduction reaction

Construction

Anode: Lithium intercalated graphite layer ($LixC_6$)

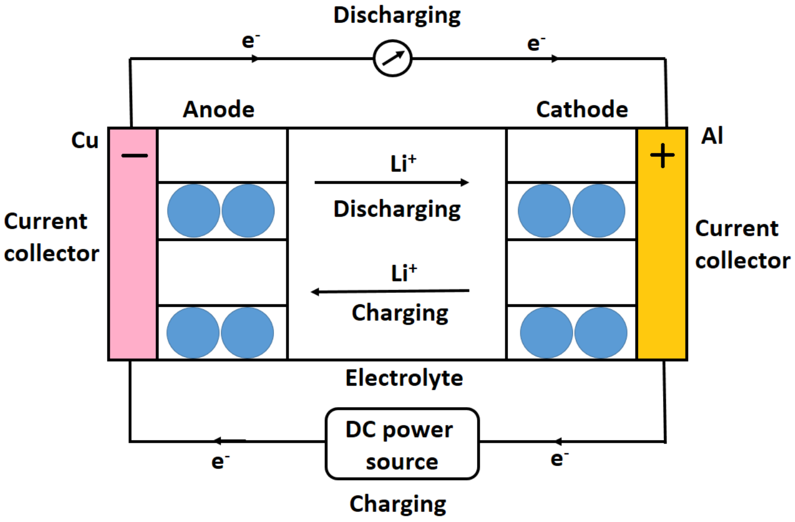
Anode current collector: Copper foil

Cathode: Partially lithiated transition metal oxide ($LiCoO_2$)

Cathode current collector: Aluminum foil

Electrolyte: Lithium salts like LiCl, LiBr dissolved in propylene carbonate

Separator: Polyolefin polymer



Working

Anode reaction: $Li_x\rightarrow C_6 \qquad xLi^+ + xe^- + 6C$

Cathode reaction: $Li_{1-x}CoO_2 + xLi^+ \rightarrow xe^- \qquad LiCoO_2$

Overall reaction: $Li_{1-x}CoO_2 + Li_x\rightarrow C_6 \qquad LiCoO_2 + 6C$

During ***discharge***, Li^+ ions are dissociated from the anode and then migrate from the anode to cathode through the electrolyte. Electrons travel through an external circuit. This process creates an electric current that can power a device or system.

*During **Charging:*** Li^+ ions move from the cathode to the anode through the electrolyte.

Application of Lithium-ion battery

- They are commonly used in smart phones, tablets, laptops
- They are used in medical devices
- They are used in spacecraft and satellites
- They are used in electric cars.