

**First Semester B.E./B.Tech. Degree Examination, Feb./Mar. 2022**  
**Engineering Chemistry**

Time: 3 hrs.

Max. Marks: 100

**Note: Answer any FIVE full questions, choosing ONE full question from each module.**

**Module-1**

- 1 a. What are Reference Electrodes? Explain the construction and working of Calomel Electrode. (07 Marks)  
b. Define Single Electrode Potential. Derive Nernst equation for Single Electrode Potential. (07 Marks)  
c. Explain the construction and working of Li – ion battery. Mention its applications. (06 Marks)

**OR**

- 2 a. Explain Primary, Secondary and Reserve batteries with an example. (06 Marks)  
b. Explain the experimental determination of pH by using glass electrode. (07 Marks)  
c. A cell consists of Copper rod dipped in 5M CuSO<sub>4</sub> solution and Iron rod dipped in 0.05 M FeSO<sub>4</sub> solution. Given  $E_{Cu}^0 = +0.34V$  and  $E_{Fe}^0 = -0.44V$ . Write Cell representation, Cell reactions and calculate Emf of the cell. (07 Marks)

**Module-2**

- 3 a. Define Corrosion. Describe Electrochemical theory of corrosion by taking Iron as an example. (07 Marks)  
b. What is Cathodic Protection? Explain Sacrificial Anodic method and Impressed Current method of Cathodic protection. (07 Marks)  
c. What is Metal Finishing? Mention technological importance of Metal Finishing. (06 Marks)

**OR**

- 4 a. Explain the factors affecting the corrosion rate :  
i) Ratio of anodic to cathodic areas.  
ii) Nature of the corrosion product.  
iii) pH. (06 Marks)  
b. What is Corrosion Penetration Rate? A piece of corroded plate was found in the submerged ocean vessel. It was estimated that the original area of the plate was 10 inch<sup>2</sup> and that approximately 2.6kg had corroded away during the submersion for a period of 10 years. Calculate Corrosion Penetration Rate (CPR) in terms of mpy and mmy. Given density ( $\rho$ ) of iron = 7.9 g/dm<sup>3</sup>  
mpy  $\rightarrow k = 534$   
mmy  $\rightarrow k = 87.6$ . (07 Marks)  
c. What is Electroless Plating? Write the differences between Electroplating and Electroless plating. (07 Marks)

**Module-3**

- 5 a. What are Conducting Polymers? Explain the mechanism of conduction in Polyaniline. (07 Marks)  
b. Explain the synthesis, properties and applications of Poly Lactic Acid. (06 Marks)  
c. What are Nanomaterials? Explain the synthesis of Nanomaterials by Sol – gel process. (07 Marks)

**OR**

- 6 a. What are Polymer Composites? Explain the synthesis and applications of Kevlar fibre. (07 Marks)  
b. Explain any two size dependent properties of Nanomaterials. (06 Marks)  
c. Write a note on Fullerene and mention its applications. (07 Marks)

**Module-4**

- 7 a. What is Green Chemistry? Explain briefly any six basic principles of Green Chemistry. (07 Marks)  
b. Describe the production of hydrogen by Photocatalytic Water Splitting Method. (06 Marks)  
c. Explain the synthesis of Paracetamol by Conventional and Green Route Method. (07 Marks)

**OR**

- 8 a. Explain the impacts of Oxides of Nitrogen ( $\text{NO}_x$ ) and Oxides of Sulfur ( $\text{SO}_x$ ) on the Environment. (06 Marks)  
b. Explain the working of Photovoltaic cell, with a neat diagram. (07 Marks)  
c. Describe working of Methyl alcohol – Oxygen fuel cell [ $\text{CH}_3\text{OH} - \text{O}_2$ ] with a neat diagram. Mention its applications. (07 Marks)

**Module-5**

- 9 a. Explain Theory, Instrumentation and Applications of Colorimeter. (07 Marks)  
b. Explain the principle of Volumetric analysis and requirement of Volumetric analysis. (06 Marks)  
c. Define Biological Oxygen demand and Chemical Oxygen demand.  
25 ml of waste water required 18.0ml and 25.2ml of 0.1N FAS solution for sample and blank titration respectively. Calculate COD of the waste water sample. (07 Marks)

**OR**

- 10 a. Explain applications of Conductometry :  
i) Strong acid Vs Strong base      ii) Weak acid Vs Strong base. (07 Marks)  
b. Define the following units of Standard Solution :  
i) Normality      ii) Molarity      iii) PPM. (06 Marks)  
c.  $25\text{m}^3$  of hard water sample titrated against 0.01M EDTA solutions consumed  $18.0\text{ cm}^3$  of EDTA solution.  $25\text{cm}^3$  same sample of hard water was boiled, filtered and titrated against 0.01M EDTA solution consumed  $12.0\text{ cm}^3$  EDTA solution. Calculate Total, Permanent and Temporary hardness of the water sample. (07 Marks)



Department: Chemistry

QP 2022 odd sem

Subject with Sub. Code: Engg Chemistry: 1<sup>st</sup> 21 CHE12

Name of Faculty: Sneha S Kulkarni

Q.No.	Solution and Scheme	Marks
	<b>Module I</b>	
1a.	<p>What are Reference electrodes? Explain the construction and working of calomel electrode</p>	7M
	<p>The electrode with known potential used to determine the potential of unknown or test electrode is known as reference electrode.</p>	1M
	<p>Construction and working of calomel electrode</p>	
		1M
	<p>→ Calomel electrode is secondary reference electrode</p>	
	<p>→ Electrode representation  <math>Pt(s), Hg(l), Hg_2Cl_2(s)   KCl(aq) [sat.]</math></p>	1M

### Construction

- Calomel electrode consists of two concentric tubes namely inner tube & outer tube
- Inner tube contains Pt wire coated with mercurous chloride in Hg. Small hole at the bottom of inner tube establish the contact between external KCl soln and  $Hg_2Cl_2$  in Hg paste.
- Outer tube contains saturated KCl & hole at the bottom of outer tube is called as porous plug which establish the contact between external analyte solution with that of internal saturated KCl solution.
- There is a provision for adding more KCl

1M

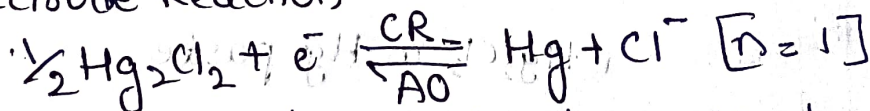
### Working:

Depending on the electrode to which the calomel electrode connected, it acts as anode or cathode.

The electrode is reversible to chloride ions and it depends on the concentration of KCl solution.

1M

### Electrode Reaction



1M

Forward reaction indicates cathodic reduction & backward reaction indicates anodic oxidation.

As the KCl concentration increases, the electrode potential decreases. At 298 K Sat. KCl soln the electrode potential observed is 0.244 V. It obeys Nernst equation.

$$E = E^\circ - 0.0591 \log [Cl^-] \quad \text{where } n = 1$$

1M

16. Define single electrode potential. Derive Nernst equation for single electrode potential  
Single electrode potential

7M

It is the potential developed at the interface of substance and its solution at unit activity of ionic species, at 298K and at 1 atm gas pressure if it is a gas electrode.

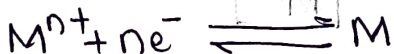
1M

Nernst equation depends upon 3 quantities

- System temperature
- Electrode potential
- Molar concentration of ionic species

Nernst equation was derived by Nernst in 1889.

Let the reversible reduction electrode reaction be —



1M

The above Reaction is spontaneous, then there is decrease in free energy and is equal to maximum energy available from system.

$$-\Delta G = W_{\max}$$

$$-\Delta G = nFE \quad (1)$$

where 'n' is number of moles of electrons transferred during reaction. 'F' is one Faraday of electricity. 'E' is electrode potential.  $\Delta G$  is change free energy. 'nF' is number of coulombs of charge that is transferred during the reaction.

1M

Std free energy change is given by

$$-\Delta G^{\circ} = nFE^{\circ} \quad (2)$$

where  $\Delta G^{\circ}$  = std. free energy change  
 $E^{\circ}$  = std. electrode potential

Q.No.

By van't Hoff reaction isotherm, change in free energy is equated to equilibrium constant and it is given by, —

$$\Delta G = -RT \ln K_{eq} + RT \ln Q \quad (3)$$

where 'Q' is the reaction quotient  
R is molar gas constant, T is system temperature in kelvin, Also, std. change in free energy is given by —

$$\Delta G^\circ = -RT \ln K_{eq} \quad (4)$$

From equation (3) & (4)

$$\Delta G = \Delta G^\circ + RT \ln \frac{[M]}{[M^{n+}]} \quad (5)$$

By definition  $[M] = 1$   
Substitute the value of  $\Delta G$  &  $\Delta G^\circ$  in equation (5)

$$-nFE = -nFE^\circ + RT \ln \frac{1}{[M^{n+}]} \quad (6)$$

Divide whole equation by  $-nF$

$$E = E^\circ - \frac{RT}{nF} \ln \frac{1}{[M^{n+}]} \quad (7)$$

$$E = E^\circ + \frac{RT}{nF} 2.303 \log [M^{n+}] \quad (8)$$

$$= E^\circ + \frac{2.303 \times 8.314 \times 298}{n \times 96500} \log [M^{n+}]$$

$$= E^\circ + \frac{0.0591}{n} \log [M^{n+}] \quad (9)$$

where  $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ ,  $T = 298 \text{ K}$

$F = 96500 \text{ C mol}^{-1}$

Equation 8 & 9 are called as Nernst equation

1M

1M

1M

1M

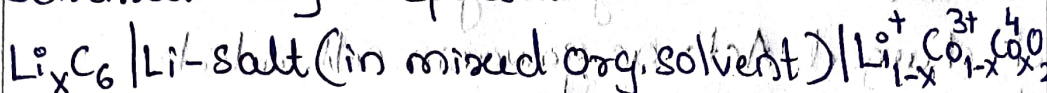
1c. Explain the construction and working of Li-ion battery. Mention its applications.

6M

Construction

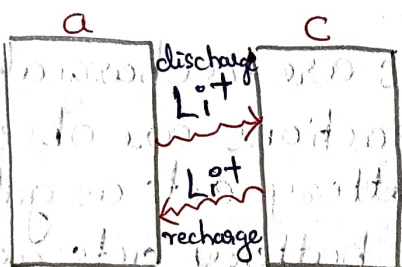
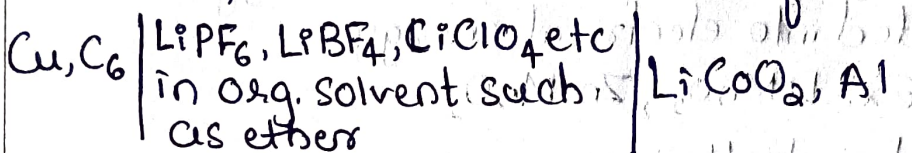
→ It is secondary rechargeable battery

Schematically represented as



1M

However, actual construction refers



1M

Anode material: Highly crystallised special carbon

Cathodic material:  $LiCoO_2$

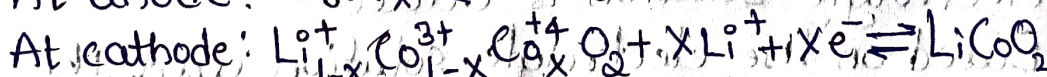
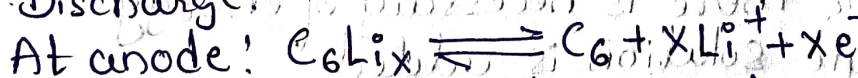
Electrolyte:  $LiPF_6, LiBF_4, LiClO_4$  mixed in organic solvent such as ether

2M

Separator: Microporous polypropylene

Working:

Discharge:



1M

Reactions in the backward direction occur during recharge.

Cell potential: 3.7V

Applications:

Used in calculators, cameras, cellular phones, medical instruments, television sets, Laptop computers, camcorders etc.

1M

2a. Explain Primary, Secondary and Reserve batteries with an example

6M

Primary batteries

The batteries are irreversible and cannot be recharged again once it is discharged. Acts as galvanic cell while discharging where chemical energy is converted into electrical energy.

Ex:  $\text{LiMnO}_2$ ,  $\text{Zn+MnO}_2$

2

Secondary batteries:

The batteries are rechargeable and reversible reactions are observed. While discharge battery acts as galvanic cell and recharge battery acts as electrolyte cell with reversible polarity.

Ex: NiMH<sub>2</sub> battery

NiCd battery

Li-ion battery

2

Reserve battery:

One of the important battery component is kept isolated. say electrolyte solution. Whenever there is necessary of energy, electrolyte solution is added.

Based on the electrolyte solution used, the battery is divided into 3 types

2

1) Acid activated ex:  $\text{Pb}|\text{H}_2\text{SO}_4|\text{PbO}_2$

2) Alkali activated ex:  $\text{Ni}|\text{NaOH}|\text{Cd}$

3) Water activated, ex:  $\text{Mg}|\text{seawater}|\text{MgO}_2$

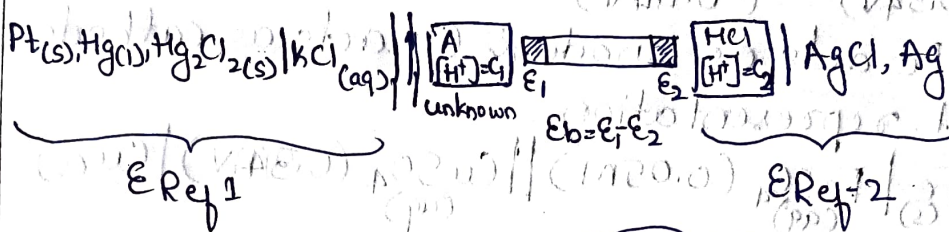
Such type of batteries are called as reserve batteries.



2b Explain the experimental determination of pH by using glass electrode

7M

A cell is constructed by coupling glass electrode and a reference electrode such as calomel electrode or silver chloride electrode as shown below. —



1M

Glass membrane electrode

Cell potential is calculated as —

$$E_{\text{cell}} = E_R - E_L$$

1M

$$E_R = E_q \text{ (Right side electrode potential)}$$

$$= E_q^{\circ} - 0.0591 \text{ pH at } 298 \text{ K}$$

$$\text{where } E_q^{\circ} = \text{constant}$$

1M

Left side electrode potential  $E_L = E_{\text{Ref 1}}$

1M

$$E_L = E_{\text{Ref 1}} = E_{\text{SCE}}$$

$$\text{Cell potential } E_{\text{cell}} = E_q^{\circ} - 0.0591 \text{ pH} - E_{\text{SCE}}$$

1M

$$\text{pH} = \frac{E_q^{\circ} - E_{\text{SCE}} - E_{\text{cell}}}{0.0591}$$

1M

$$\text{pH} = \frac{k' - E_{\text{cell}}}{0.0591} \text{ at } 298 \text{ K}$$

1M

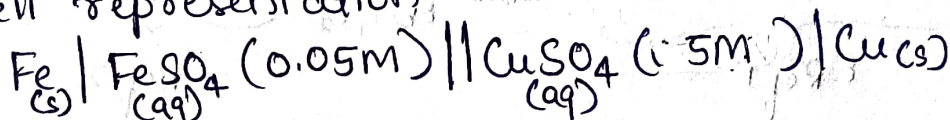
$k'$  is called glass electrode membrane assembly constant. In this way the pH of the test solution is determined.

2c. A cell consists of copper rod dipped in 5M  $\text{CuSO}_4$  solution & Iron rod dipped in 0.05M  $\text{FeSO}_4$  solution. Given  $E_{\text{Cu}}^{\circ} = +0.34\text{V}$  &  $E_{\text{Fe}}^{\circ} = 0.44\text{V}$ . Write the cell representation, cell reactions and calculate EMF of the cell.

$$E_{\text{Cu}}^{\circ} > E_{\text{Fe}}^{\circ}$$

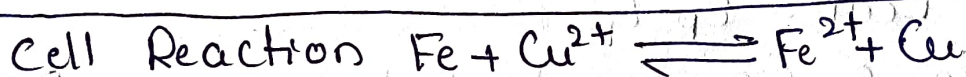
$$(0.34\text{V}) \quad (-0.44\text{V})$$

$\therefore$  Fe acts as anode & Cu acts as cathode.  
cell representation



Anodic oxidation:  $\text{Fe} \longrightarrow \text{Fe}^{2+} + 2\text{e}^{-}$

Cathodic reduction:  $\text{Cu}^{2+} + 2\text{e}^{-} \longrightarrow \text{Cu}$   $(n=2)$



$$E_{\text{cell}}^{\circ} = E_{\text{R}}^{\circ} - E_{\text{L}}^{\circ}$$

$$= E_{\text{Cu}}^{\circ} - E_{\text{Fe}}^{\circ}$$

$$= 0.34 - (-0.44)$$

$$= 0.34 + 0.44$$

$$= 0.78\text{V}$$

$$E_{\text{cell}} = E_{\text{cell}}^{\circ} + \frac{2.303 \cdot RT}{nF} \log \frac{[\text{Cu}^{2+}]}{[\text{Fe}^{2+}]}$$

$$= 0.78 + \frac{2.303 \times 8.314 \times 298}{2 \times 96500} \log \frac{[5\text{M}]}{[0.05]}$$

$$= 0.78 + 0.02955 \log(100)$$

$$= 0.78 + 0.0591$$

$$= 0.83\text{V}$$

$$\therefore E_{\text{cell}} = 0.83\text{V}$$

## Module 2

3a Define Corrosion. Describe Electrochemical theory of corrosion by taking Iron as an example.

7M

Corrosion:

Destruction or disintegration of metals when exposed to the surrounding corrosive starting at their surface by either chemical or electrochemical means is metallic corrosion.

Electrochemical theory of corrosion by taking Iron as an example.

This corrosion is characterized by the formation of small galvanic cells due to heterogeneities. Part of metal act as anode and another part act as cathode.

Anodic part of the metal undergoes destruction by oxidation. Steel (Iron) undergoes corrosion by following reaction:

Anodic reaction:  $\text{Fe} \longrightarrow \text{Fe}^{2+} + 2\text{e}^-$

Reduction depends on the contents in the medium. Some important reactions are —  
H<sub>2</sub> evolution type?

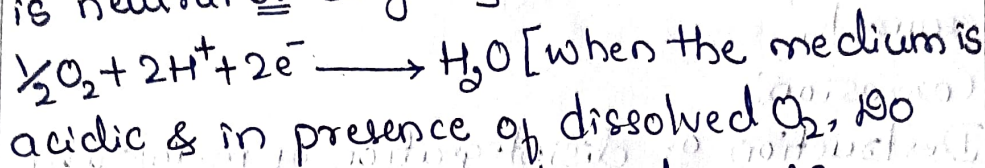
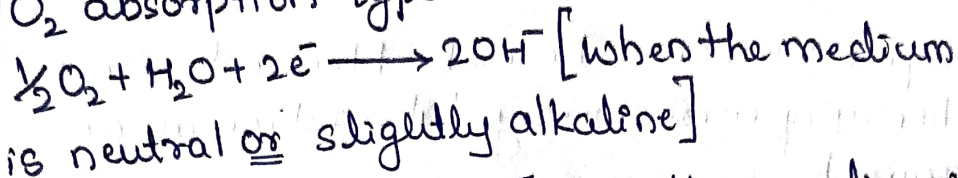
$2\text{H}^+ + 2\text{e}^- \longrightarrow \text{H}_2$  [when the medium is acidic]

$2\text{H}_2\text{O} + 2\text{e}^- \longrightarrow \text{H}_2 + 2\text{OH}^-$  [when the medium is neutral or slightly alkaline]

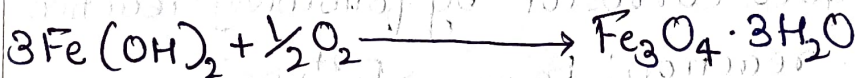
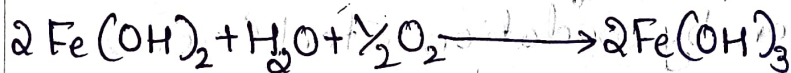
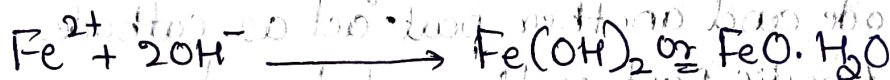
Hydrogen evolution type is characterized by the presence of large anodic area and a small cathodic area. Corrosion is uniform & less aggressive. Higher the acidity, higher is corrosion rate.

Q.No.

$O_2$  absorption type:



Oxygen absorption type is characterized by the presence of small anodic area & large cathodic area. Corrosion is localised and very aggressive. Higher is the oxygen contained in the medium, higher is the corrosion rate. Ferrous hydroxide is formed as corrosion product. Excess  $O_2$  can oxidize it further to yellow rust or black rust.



3b. What is cathodic protection? Explain sacrificial anodic method & impressed current method of cathodic protection.

Cathodic protection

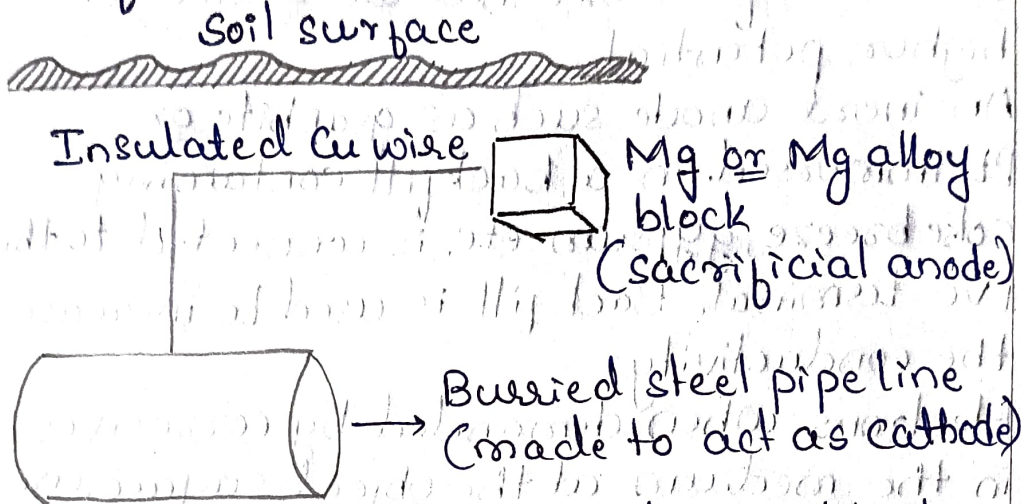
Metals undergo corrosion by oxidation or anodic oxidation.

They do not undergo corrosion by

reduction or cathodic reduction.

Protection of metal by forcefully making it to act as cathode is referred as cathodic protection.

a Sacrificial anodic protection method.



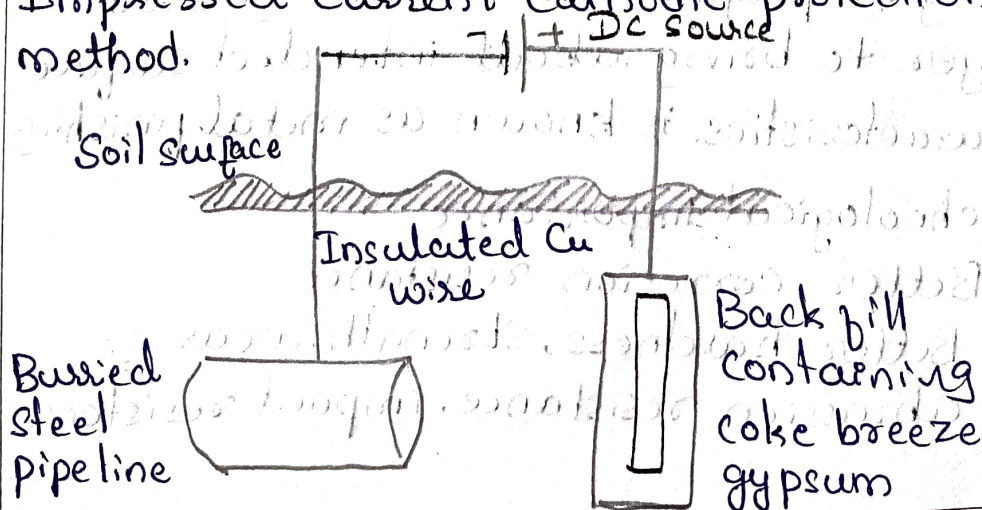
Object metal is connected to a block of an anodic metal such as Zn, Al, Mg or their alloys.

Whenever there is demand of electrons by the corrosives in the medium, anodic metal will sacrificially undergo oxidation and release the electrons. Thus, the object metal is protected.

As long as anodic metal block is existent, protection is achieved. When it disappears, fresh block is replaced.

Applications: Employed for buried pipelines used for water or oil, water tanks, ocean going ships, piers etc.

b. Impressed current cathodic protection method.



Object metal is connected to the -ve terminal of an external DC source with higher potential.

An inert anode such as graphite or Pt immersed in a backfill containing coke breeze, gypsum etc. is connected to the +ve terminal. Backfill is used to increase the conductivity.

Electrons, when demanded by corrosives in the medium at the object surface, are supplied from the external battery and object metal is protected. As and when battery potential decreases, it is recharged.

Applications: Employed for buried pipe lines used for water or oil, water tanks, ships, piers etc.

3c. What is metal Finishing? Mention its technological importance of metal Finishing. 6M

Metal Finishing

Process of surface modification by way of deposition of another metal or alloy or polymer or ceramic or oxide layer to bring about intended surface characteristics. is known as metal finishing

Technological importance

- i) Better corrosion resistance
- ii) Better hardness, strength, wear or abrasion resistance, impact resistance



Q.No.	Solution and Scheme	Marks
ii)	<p>Nature of the corrosion product</p> <p>Some metals and alloys exhibit an inherent property of forming a protective coating of their compounds when exposed to different media. When the corrosion product film over object metal surface is</p> <ul style="list-style-type: none"> <li>i) inert to metal &amp; medium</li> <li>ii) Continuous (non porous)</li> <li>iii) Adherent to the metal surface, it starts acting as a barrier between the metal &amp; medium. Further corrosion of the metal is prevented. This is known as passivation of metals. Some of metal &amp; medium combinations are known to give protective coatings</li> </ul> <p style="margin-left: 40px;">mild steel - conc <math>H_2SO_4</math></p> <p style="margin-left: 40px;">Al - fuming <math>HNO_3</math></p>	2
iii)	<p>pH</p> <p>Lower pH suggests that the acidic medium and many of the metals undergo severe corrosion except those with higher reduction electrode potentials. Higher pH represents alkalinity and many metals exhibit resistance. However, too higher alkalinity may lead to corrosion of the metal. Iron exhibits lower rate of corrosion in a medium of pH = 5.0 in absence of <math>O_2</math>. At the same pH, with dissolved <math>O_2</math>, it exhibits relatively higher rate. At pH values below 4.5, it exhibits aggressive corrosion irrespective of presence of <math>O_2</math> or absence</p>	2



4b What is the corrosion penetration rate?  
 A piece of corroded plate was found in the submerged ocean vessel. It was estimated that original area of plate was 10 inch<sup>2</sup> and that approximately 2.6 kg had corroded away during the submersion for a period of 10 years. Calculate CPR in terms of mpy and mm/yr. Given density (ρ) of iron = 7.9 g/dm<sup>3</sup>

mpy → k = 534  
 mm/yr → k = 87.6

7M

Corrosion penetration rate

The speed at which a metal deteriorates due to chemical or electro-chemical reaction when it is exposed to the corrosive. or The speed at which corrosion spreads to the inner portions of a material.

To calculate CPR in mpy

	Given	CPR in mpy
K	-	534
w (wt. loss)	2.6 kg	2.6 × 1000 × 1000 mg
ρ or D	7.9 g/dm <sup>3</sup>	7.9 g/dm <sup>3</sup>
A	10 inch <sup>2</sup>	10 inch <sup>2</sup>
T	10 years	10 × 365 × 24
CPR		?

3

$$\begin{aligned}
 \text{CPR} &= \frac{kw}{DAT} \\
 &= \frac{534 \times 2.6 \times 1000 \times 1000}{7.9 \times 10 \times 10 \times 365 \times 24} \\
 &= 200.62 \text{ mpy}
 \end{aligned}$$

To calculate CPR in mmpy

	Given	CPR in mmpy
K		87.6
w (wt loss)	2.6 kg	$2.6 \times 1000 \times 1000 \text{ mg}$
P or D	$7.9 \text{ g/dm}^3$	$7.9 \text{ g/dm}^3$
A	$10 \text{ inch}^2$	$10 \times 2.54 \times 2.54 \text{ cm}^2$
T	10 years	$10 \times 365 \times 24$
CPR		?

$$\text{CPR} = \frac{Kw}{DAT}$$

$$= \frac{87.6 \times 2.6 \times 1000 \times 1000}{7.9 \times 10 \times 2.54 \times 2.54 \times 10 \times 365 \times 24}$$

$$= \frac{227760000}{44647652.64}$$

$$= 5.1012 \text{ mmpy}$$

4C What is electroplating? Write the difference between electroplating & electroless plating

The process of deposition of a thin and uniform layer of metal or metal alloy on to the electrically conducting object surface electrolysis is known as electroplating.

Difference between electroplating and electroless plating.

Property	Electroplating	Electroless plating
1. Driving force	Power supply	Autocatalytic redox reaction
2. Site of oxidation reaction	Separate anode	Object surface to be plated

Q.No.	Property	Solution and Scheme		Marks
		Electroplating	Electrolessplating	
3	Site of reduction Reaction	Object surface to be plated	Surface activated object	
4	Oxidation reaction	When anode is active $M \rightarrow M^{n+} + ne^{-}$ When anode is inert $\frac{n}{2} H_2O \rightarrow \frac{n}{2} H_2 + \frac{n}{2} O_2 + ne^{-}$	$R \rightarrow O + ne^{-}$ where R = reducing agent O = Oxidised species.	
5	Reduction Reaction	$M^{n+} + ne^{-} \rightarrow M$	$M^{n+} + ne^{-} \rightarrow M$	6M
6	Time taken for deposition	Short	Long	
7	Throwing power	Low	High	
8	Plating cost	Low	High	
9	Nature of deposit	Pure metal <u>or</u> definite alloy, hard deposit	Usually, metal contaminated with R <u>or</u> O derived species; harder deposit	
10	Features of deposit	May be porous, less corrosion resistant	Non porous, relatively hard and more corrosion resistant.	

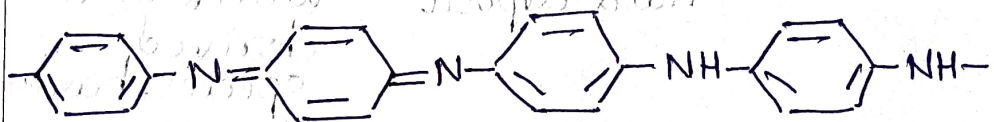
## Module-3

5a. What are conducting polymers? Explain the mechanism of conduction in Polyaniline  
Conducting Polymers

Linear, organic polymers with conjugate single and double bonds with suitable doping by oxidation or reduction or proton etc, with delocalised  $\pi$  electron system, exhibiting conductivity equivalents of metals are referred to as 'conducting polymers'.

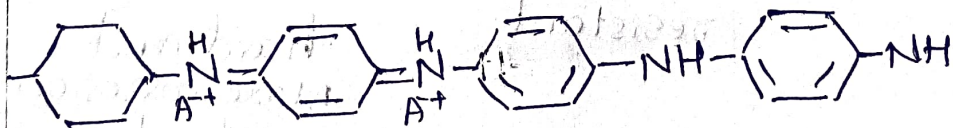
Mechanism of conduction in Polyaniline

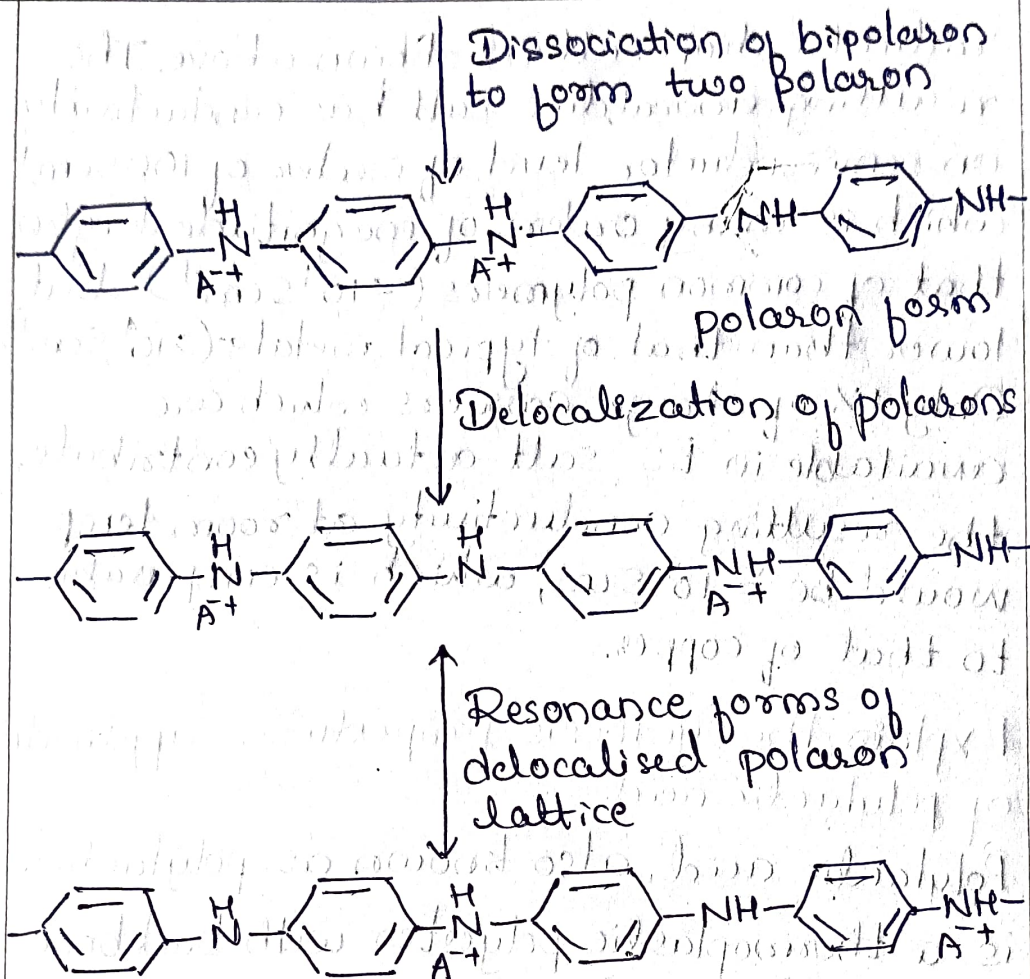
It has been demonstrated that the polyaniline chain can be formed by various combinations of two repeating units. Owing to this, PANI has many unique properties and electronic conduction mechanisms that distinguish it from the rest of the conducting polymers. For example, the conductivity of PANI varies with the extent of oxidation.



polyemeraldine

$H^+A^-$  ↓ protonation





6

Among the various oxidation states that PANI can exist in, the one that can be doped to a highly conductive state is the moderately oxidized emeraldine base [EB]. This form of PANI has a structure which consists of equal proportion of amine ( $-NH-$ ) and imine ( $-N=$ ) sites. Through protonic acid doping, imine sites are protonated by acids  $HA$  ( $HCl$ ,  $HNO_3$ ,  $H_2SO_4$  etc) to the bipolaron (di-cation salt) form. The bipolaron then undergoes a further rearrangement to form the delocalized polaron lattice which is a polysemiquinone

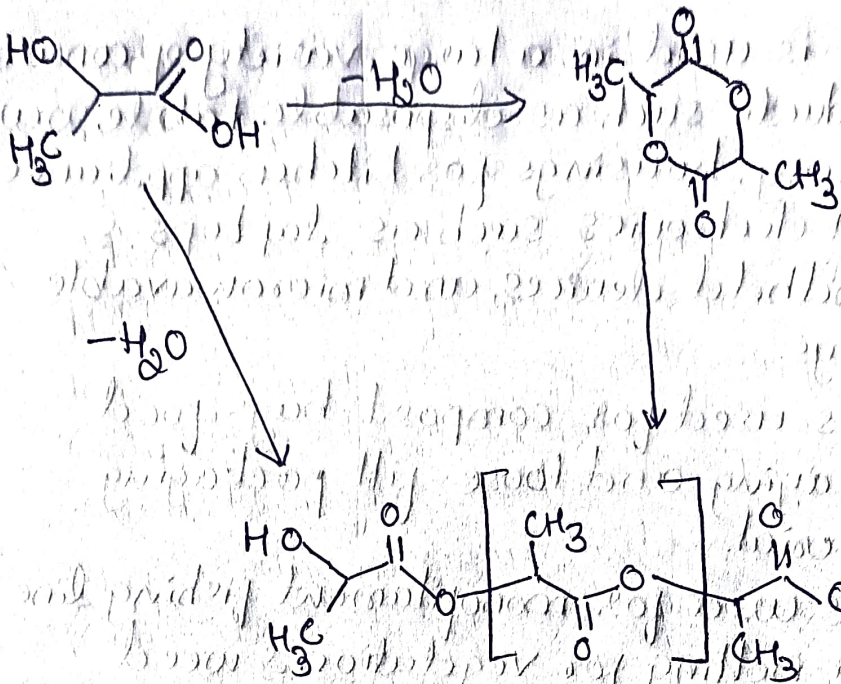
radical cation/salt. as shown above. The resulting emeraldine salt has conductivity on semiconductor level of order of  $100 \text{ Scm}^{-1}$ , which is many orders of magnitude higher than that of common polymers ( $< 10^9 \text{ Scm}^{-1}$ ) but lower than that of typical metals ( $> 10^4 \text{ Scm}^{-1}$ ). Only 1% of charge carriers which are available in ES salt actually contribute, the resulting conductivity at room temp would be  $\approx 10^5 \text{ Scm}^{-1}$ , which is comparable to that of copper.

56 Explain the synthesis, properties & applications of polylactic acid. 6M

Polylactic acid, also known as polylactide is a thermoplastic polyester with backbone formula  $(\text{C}_3\text{H}_4\text{O}_2)_n$  or  $[-\text{C}(\text{CH}_3)\text{HC}(=\text{O})\text{O}]_n$  formally obtained by condensation of lactic acid  $\text{C}(\text{CH}_3)(\text{OH})\text{HCOOH}$ , with loss of water (hence its name).

Synthesis:

The direct (synthesis) condensation of lactic acid monomers can also be used to produce PLA. Two main monomers are used: lactic acid, and the cyclic diester, lactide. This process needs to be carried out at less than  $200^\circ\text{C}$ . This reaction generates one equivalent of water for every condensation (esterification) step.



### Properties

- 1 PLA polymers range from amorphous glassy polymer to semi-crystalline and highly crystalline polymers with a glass transition  $60-65^{\circ}\text{C}$ , a melting temperature  $130-180^{\circ}\text{C}$ .
- 2 PLA can be withstand temperatures of  $110^{\circ}\text{C}$ .
- 3 Introducing crosslink structures have been used to enhance the mechanical properties of PLA polymers.
- 4 Polylactic acid can be processed like most thermoplastics into fiber and film.
- 5 PLA is soluble in a range of organic solvents.
- 6 PLA objects can be fabricated by 3D printing, casting, injection moulding, extrusion, machining & solvent welding.

### Applications

Q.No.	Solution and Scheme	Marks
1	PLA is used in a large, variety of consumer products such as disposable, table ware, cutlery, housings for kitchen appliances and electronics such as laptops & handheld devices, and microwavable trays.	
2	It is used for compost bags, food packaging and loose-fill packaging material.	
3	It is used for monofilament fishing line and netting for vegetation & weed prevention.	
4	It is used for disposable garments, feminine hygiene products and diapers.	
5	It is used for sandbags, planting pots, binding tapes and ropes.	
6	Use as medical implants in the form of anchors, screws, plates, pins, rods and mesh.	
7	It is used in bone engineering, a facial volume enhancer used for treating lipoatrophy of the cheeks.	
5c	<p>What are nanomaterials? Explain the synthesis of nanomaterials, by sol-gel process.</p> <p>The sol-gel process is a wet chemical technique that uses either a chemical solution or colloidal particles to produce an integrated network (gel).</p> <p>Metal alkoxides and metal chlorides are typical precursors. They undergo</p>	7M



hydrolysis, condensation, and polycondensation reactions to form a gel.

After the drying process, the liquid phase is removed from the gel. Thermal treatment favours further polycondensation and formation of nanomaterials.

→ The different steps in sol-gel method are briefly outlined below

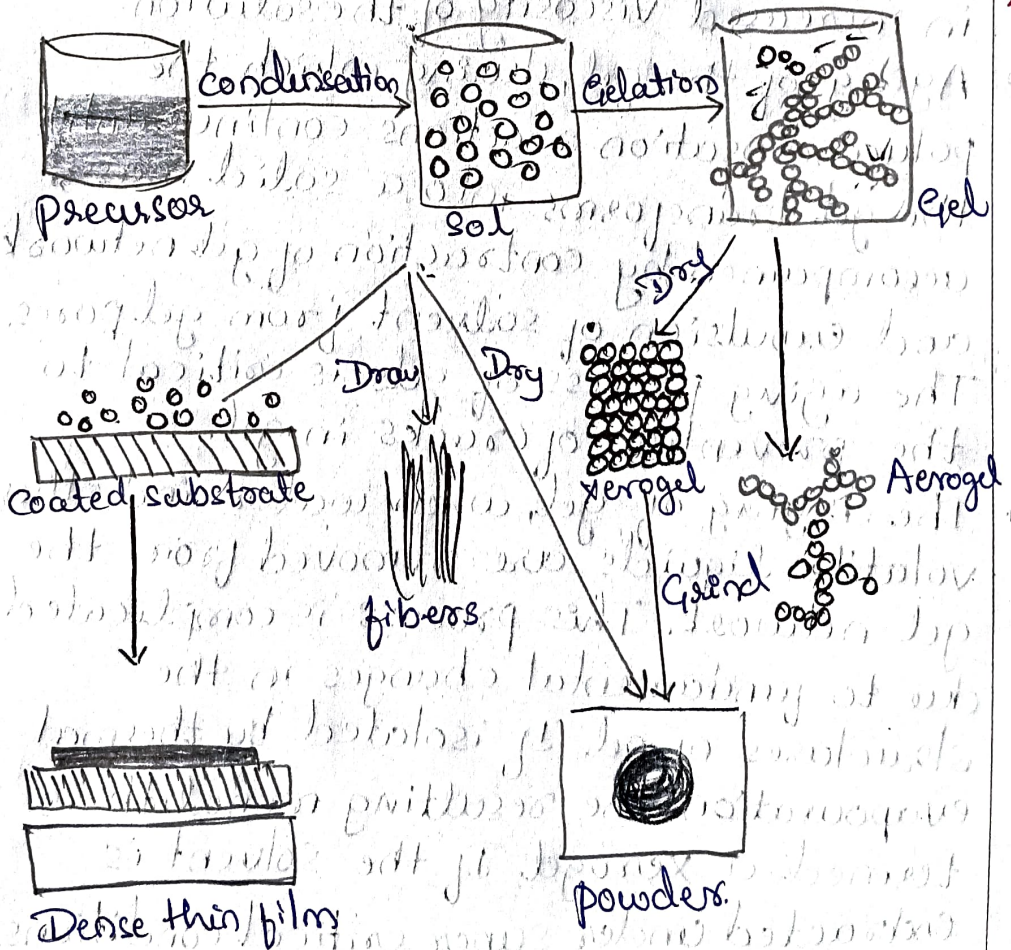
- 1 Formation of different stable solutions of alkoxide or solvated metal salt precursor.
- 2 Gelation resulting from the formation of an oxide or alcohol-bridged network by polycondensation reaction which results in increased viscosity of the solution.
- 3 Aging of the gel, during which the polycondensation reactions continue until the gel transforms into a solid mass, accompanied by contraction of gel network and expulsion of solvent from gel pores. The aging process of gels is critical to the prevention of cracks in gel.
- 4 The drying of gel, when water and other volatile liquids are removed from the gel network. This process is complicated due to fundamental changes in the structures of gel. If isolated by thermal evaporation, the resulting monolith is termed a xerogel. If the solvent is extracted under super critical conditions, the product is called aerogel.

4M

- 5 Dehydration, during which surface bound M-OH groups are removed, thus by stabilizing the gel against rehydration. This is normally achieved by calcining the monolith at temperatures upto 800°C.
- 6 Densification and decomposition of the gels at high temperatures ( $T > 800^\circ\text{C}$ ) The pores of the gel network are collapsed and remaining organic species are volatilized.

Steps involved

- i) Hydrolysis  $\text{MOR} + \text{H}_2\text{O} \rightarrow \text{MOH} + \text{ROH}$
- ii) Water condensation:  $\text{MOH} + \text{HOM} \rightarrow \text{MOM} + \text{HOH}$
- iii) Alcohol condensation:  $\text{MOH} + \text{ROM} \rightarrow \text{MOM} + \text{ROH}$



2M

## Nanomaterials definition

Nanomaterials are the materials having nanoscale dimension in at least one direction. Materials containing particles, in an unbound state or as an aggregate or as an agglomerate & where, for 50% or more of the particles in number size distribution, one or more external dimensions is in the size range 1nm to 100nm.

1M

6a What are polymer composites? Explain synthesis and applications of Kevlar fibre.

2M

1A) Polymer composites

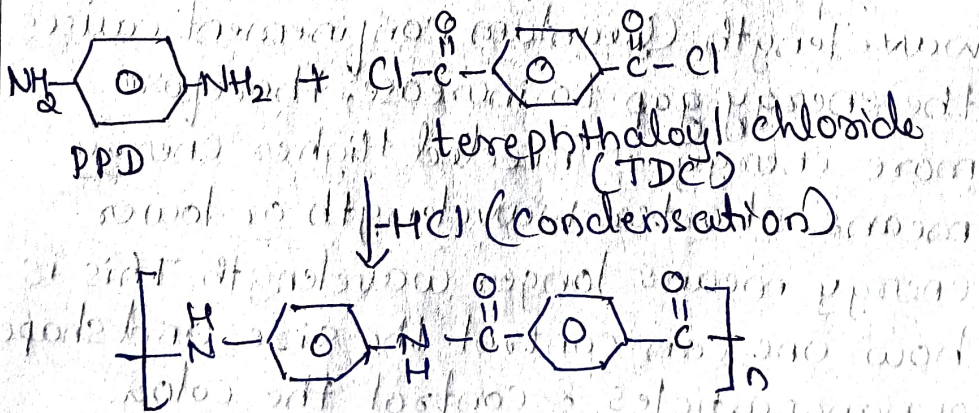
Harmonious combination of two or more materials, at least one of them being a polymer and another being reinforcing material is referred to as polymer composite.

1M

Synthesis of Kevlar fibre

It is synthesized by reacting paraphenylene diamine with terephthaloyl chloride with elimination of HCl. It is condensation polymerization reaction.

2M



Q.No.	Solution and Scheme	Marks
	<p>Applications:</p> <ul style="list-style-type: none"> <li>→ Body armour: 'Bullet proof vests' &amp; helmets</li> <li>→ Ropes &amp; cables</li> <li>→ Belts and hoses for industrial applications</li> <li>→ Composites for aircraft body parts, boats and sporting goods.</li> <li>→ Fibre-optic cables for communication, data transmission &amp; ignition.</li> <li>→ Sailing motor cycle outer wear</li> <li>→ Adhesives &amp; sealants</li> </ul>	3M
6b.	<p>Explain any two size dependent properties of nanomaterials.</p>	6M
	<p>→ Optical properties</p> <p>Nanomaterials have unique optical properties as a result of the way light interacts with their nanostructures. due to interference, scattering, surface plasmons and quantum fluorescence.</p> <p>Nanoparticles will have quantized energy states. Excitation <u>or</u> deexcitation of electrons from/to these discrete energy states happens by certain definite wavelength. Quantum confinement, causes the energy gap to increase; therefore more energy is needed. Higher energy means shorter wavelength <u>or</u> lower energy means longer wavelength. This is how one can control the size and shape of nanoparticles &amp; control the color.</p>	3

Nanoparticles of metals exhibit surface plasmon resonance (SPR). When light strikes the nanoparticle, electrons on the surface start oscillating about their position in a small space & depending on frequency of oscillation, resonating electrons absorb/scatter radiation of different wavelength.

→ Electrical properties

Substances can be classified as good conductors, semiconductors and insulators depending upon their electrical conductivity or resistivity.

The energy gap between the valence band and conduction band and the presence and number of electrons in the conduction band decides the conductivity of the material. In a good conductor like a metal, there is overlapping of VB and CB i.e. Valence band and conducting band.

Larger the number of atoms in a bulk metal and overlapping of their orbitals results in overlapping of VB with CB and energy levels are continuous and the metals are very good conductors. Some metals, which are good conductors become semiconductors or insulators as their size is reduced to nanoscale. When the number of atoms decreases like in a nanomaterial

Very few orbitals overlap and the energy levels separate or become discontinuous.

This is sometimes known as quantum confinement. Electrons do not find space to move around; instead, they are confined to very small space or nanospace. Thus, with the increased discontinuity, nanomaterials tend to become semiconductors or insulators.

Nanomaterials also show very interesting tunneling effect. An electron is seen on the other side of barrier without enough kinetic energy because of the wave property of the particles. Though, the intensity gets lowered. Also some of the nanostructures exhibit exceptional electrical conductivity like carbon nanotubes or graphene because of their unique structure.

6c Write a note on fullerene and mention its applications.

Fullerens are zero dimensional solids. It is an allotrope of Carbon  $C_{60}$ . It is a hollow spherical molecule found in carbon soot. The molecule is called fullerene because it resembled the geodesic dome designed by the American architect Buckminster Fuller. Fullerene molecules with 60 carbon atoms contain interlocked

pentagons and hexagons similar to soccer ball. They are also called bucky balls and have truncated isosahedron structure. Many other bucky balls with 70, 76, 78, 84 carbon atoms are discovered.

Properties:

$C_{60}$  Fullerene contains 12 pentagons and 20 hexagonal rings. All carbon atoms are  $sp^2$  hybridized. C-C bond length is  $1.435 \text{ \AA}$  and C=C bond length is  $1.383 \text{ \AA}$ . Diameter is  $1 \text{ nm}$ . Fullerene  $C_{60}$  is black in color and its powdery nature. density is  $1.72 \text{ g/cm}^3$ .

Refractive index is 2.2 (at  $600 \text{ nm}$  wavelength)

Resistivity is  $1014 \text{ ohm/m}$ . It sublimes at  $800 \text{ K}$ . It is most symmetrical molecule.

It is insoluble in water but sparingly

soluble in 1,2,4-Trichlorobenzene, carbon disulfide, Toluene, benzene, chloroform,  $CCl_4$ .

It is tough and thermally stable. It can be compressed to 70% of its volume. Forms endohedral and exohedral derivatives.

Applications:

Fullerenes are used as lubricants due to their spherical shape and slippery nature.

Fullerenes are used for reinforcing different structures where lightness and strength of materials is required.

Fullerenes can act as electrophiles.

They catalyse many organic reactions.

C<sub>60</sub> can theoretically take up 60 atoms of hydrogen and can be used as hydrogen storage material for fuel cells and some secondary batteries.

Alkali doped fullerenes are semiconductors at moderately high temperatures. Higher temperatures are attained with lowered cluster size to C<sub>36</sub>, C<sub>28</sub>, C<sub>20</sub> etc.

Module 4

7a.

What is Green Chemistry? Explain briefly any six basic principles of Green Chemistry

TM

Green Chemistry is defined as invention design, development and applications of chemical products and processes to reduce or to eliminate the use of and generation of substances hazardous to human health & environment.

Six principles of green chemistry

1. Better to prevent than cure

Design chemical synthesis to prevent waste. leave no waste or treat or clean up. waste prevention is necessary because of following reasons.

→ If a process produces waste, it invokes the need for its treatment/disposal which inturn amounts to additional expenditure.

→ Secondly if the waste is toxic or hazardous the release of waste into the environment leads to its pollution which



further invokes the need for treatment causing additional expenses.

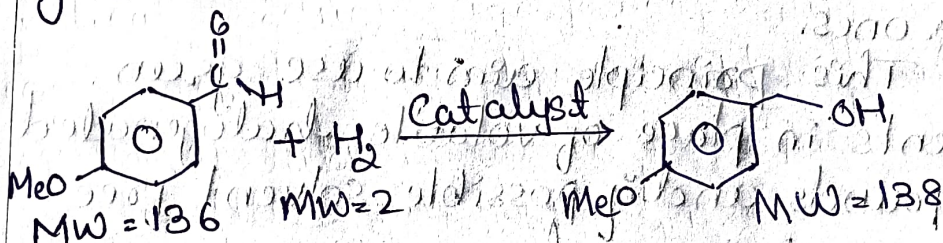
Ex! The bottom ash of thermal power station can be used as a raw material for cement and brick industry.

Effluent coming but from cleaning of machinery parts may be used as a coolant water in thermal power stations.

## 2. Atom economy:

Design, synthesize so that the final product contains the maximum proportion of starting materials.

Ex! The % atom economy of the reaction given below is \_\_\_\_\_



$$\% \text{ Atom economy} = \frac{\text{Relative MW of desired product}}{\text{Relative MW of all reactants}} \times 100$$

$$= \frac{138}{(136+2)} \times 100$$

$$= 100\%$$

## 3. Less hazardous chemical synthesis

Design, synthesize to use and generate substances with little or no toxicity to either humans or the environment.

An important example concerning the use of safe chemicals is the manufacture of polystyrene foam sheet packaging material where in chemist have

replaced the use of hazardous CFC by  $\text{CO}_2$  as blowing agent.

4. Designing safer chemicals.

Design chemical products that are fully effective & have little or no toxicity.

Ex: Benzene is the starting material for the synthesis of adipic acid. Benzene is carcinogenic & being VOC it pollutes the air.

5. Use safer solvents and reactions conditions.

Avoid using solvents, separation agents or other supporting chemicals; use If you must use these chemicals; use safer ones.

This principle aim to use green solvents in place of volatile, halogenated compounds, and if possible solvent free synthesis is preferred.

7b Describe the production of hydrogen by photocatalytic water splitting Method.

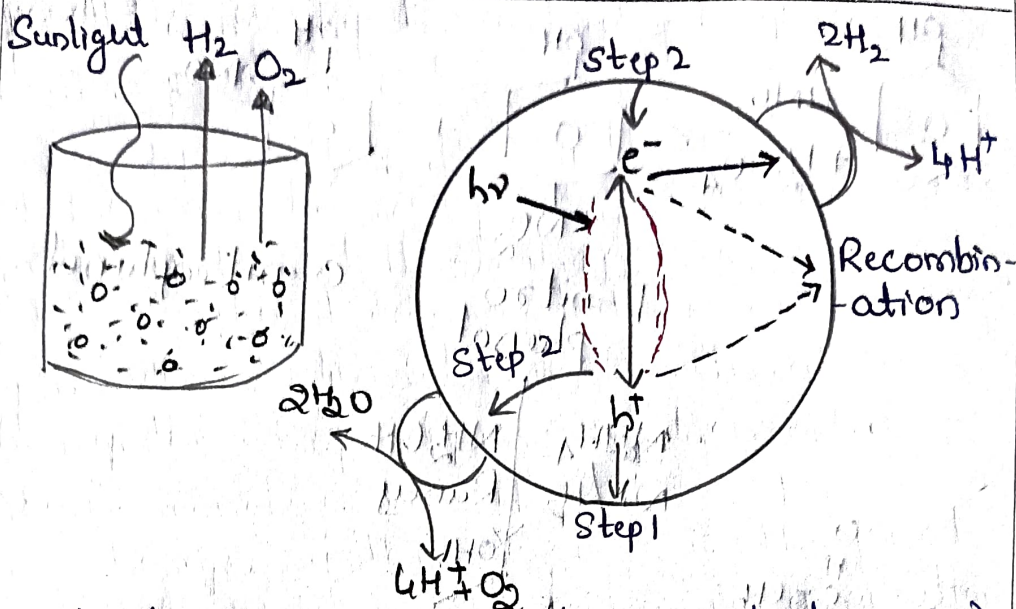
6M

Hydrogen production by photo-catalytic reaction.

Input: Photocatalytic particles, sunlight & water

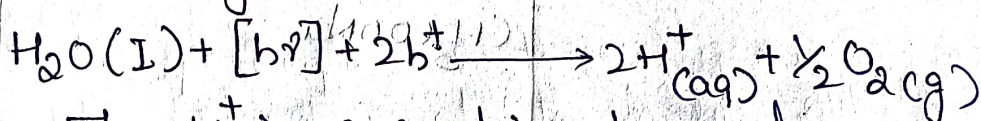
Output: Oxygen & hydrogen

→ Splitting of water to get hydrogen by using a photocatalyst & using solar energy is called photocatalytic water splitting.

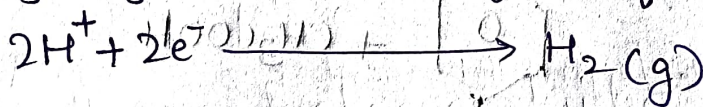


→ The light energy excites an electron ( $e^-$ ) in the catalyst.

Thus produced hole ( $h^+$ ) will react with neighbouring water molecule.



→ The  $\text{H}^+$  ions combine to produce hydrogen at the surface of the co-catalyst.



The produced hydrogen can be used as fuel in the hydrogen fuel cell.

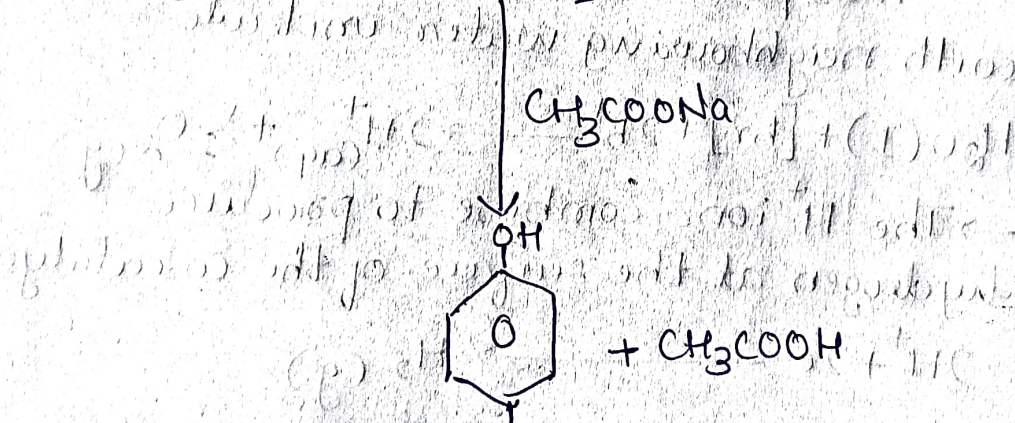
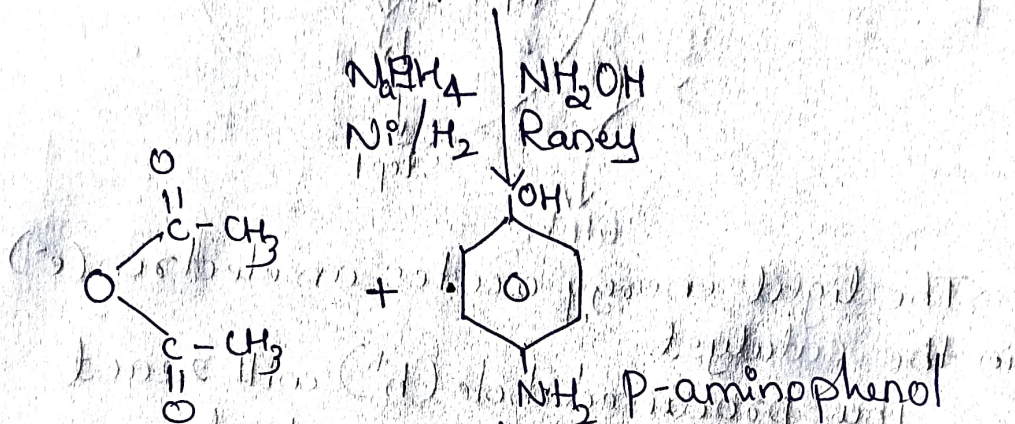
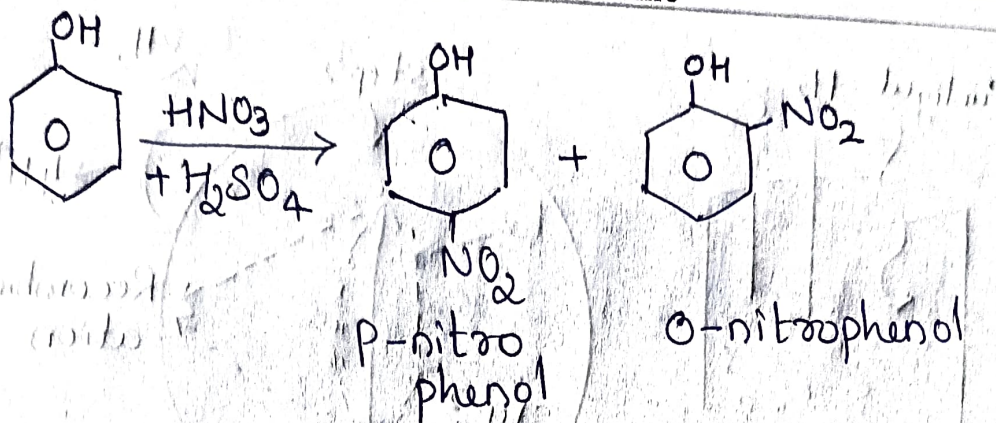
→ Here holes are oxidizing the water & electrons reduces hydrogen ions to hydrogen gas.

TC Explains the synthesis of paracetamol by Conventional and Green route method.

Synthesis of paracetamol by conventional method

4

7M



3.5M

In first step: Nitration reaction of phenol using nitrating mixture ( $H_2SO_4 + HNO_3$ ) which is an example for electrophilic aromatic Reaction. p-nitrophenol is stable & only it is further used for synthesis of paracetamol

In 2<sup>nd</sup> step:

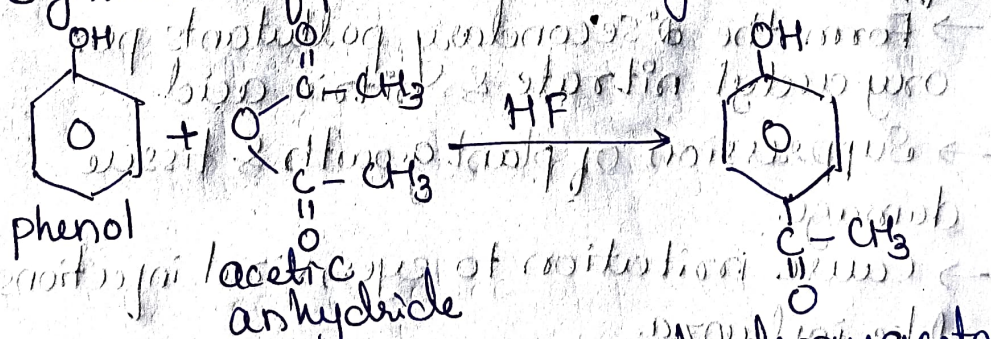
Reduction of nitro group (-NO<sub>2</sub>) to amine group (-NH<sub>2</sub>) using reducing agents such as sodium borohydride (NaBH<sub>4</sub>), hydroxylamine (NH<sub>2</sub>OH), metals in acidic medium (Sn/HCl) or using Raney Ni in presence of H<sub>2</sub>(g).

In 3<sup>rd</sup> step:

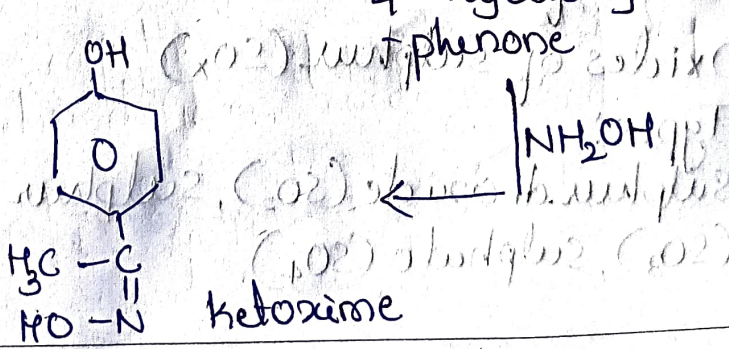
Nucleophilic addition reaction of p-aminophenol with acetic anhydride in presence of sodium acetate. The N atom (of NH<sub>2</sub>) is more nucleophilic than the O atom (of OH) & hence the reaction occurs with NH<sub>2</sub> group.

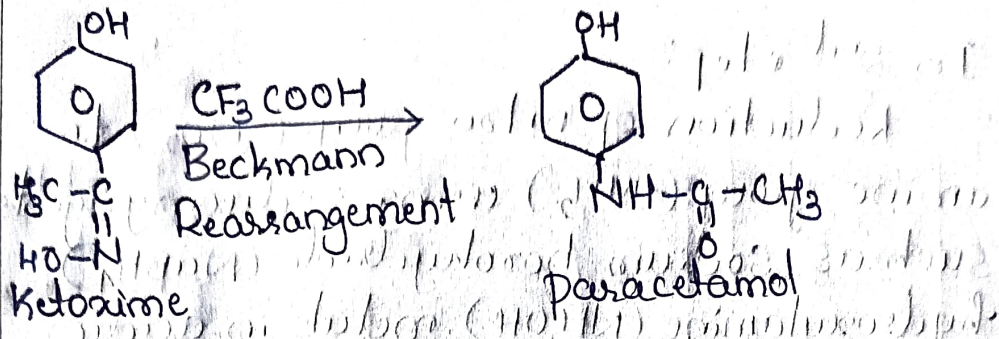
The drawback of this method is the % atom economy calculated for this synthesis is  $\cong 36\%$ .

Synthesis of paracetamol by Green Route



3.5M





Atom economy calculated for this green synthesis = 58%

8a. Explain the impacts of oxides of Nitrogen ( $NO_x$ ) and oxides of  $SO_x$  on the environment. 6M

Oxides of Nitrogen ( $NO_x$ )

Types: Nitrogen oxide ( $NO$ ), Nitrogen dioxide ( $NO_2$ ), Nitrous oxide ( $N_2O$ ), Nitrate ( $NO_3$ )

Source of production:

Burning of fuels, biomass burning, byproduct in the manufacturing of fertilizers.

Effects on humans & environment

- Form the 2° secondary pollutants peroxy acetyl nitrate & nitric acid
- Suppression of plant growth & tissue damage.
- Cause irritation to eyes, viral infections like influenza.

Oxides of sulphur ( $SO_x$ )

Types: sulphur dioxide ( $SO_2$ ), sulphur trioxide ( $SO_3$ ), sulphate ( $SO_4$ )

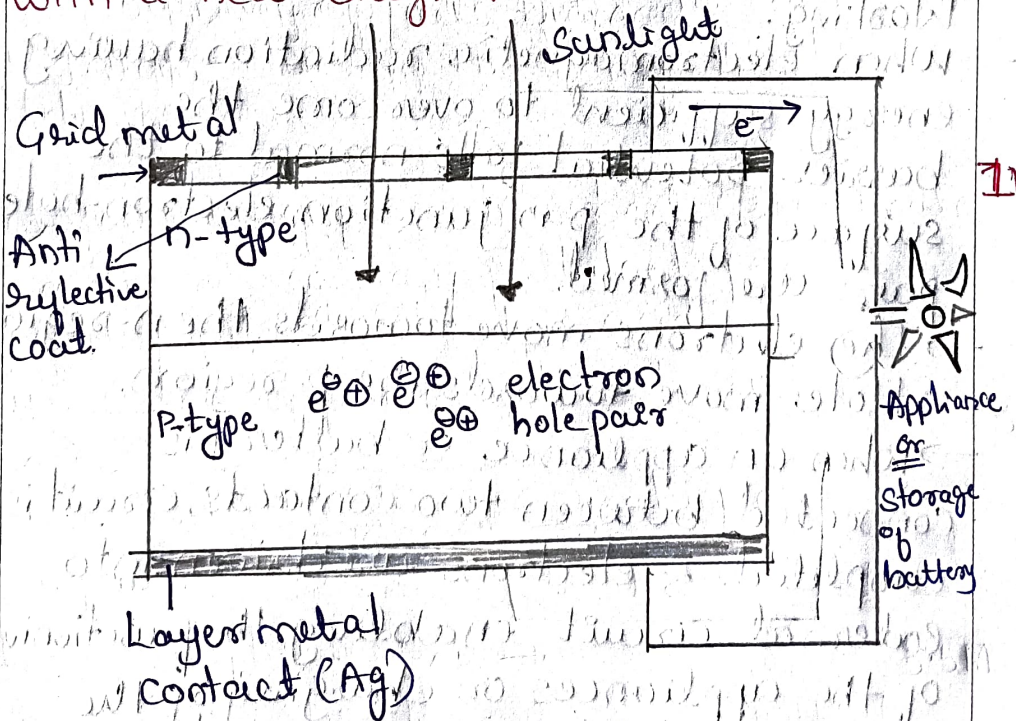
Source of production

- Combustion of sulphur containing fuel
- Petroleum extraction & refining
- Paper manufacturing, municipal incineration
- Ore smelting for metal extraction

Effects on humans and Environment

- $SO_2$  cause damage to human & other animal lungs
- It is important precursor to acid rain
- adverse effects include corrosion of paint metals & injury or death to animals & plants.

8b. Explain the working of photovoltaic cell with a neat diagram



Photovoltaic cells are the devices that convert solar energy into electrical energy from semiconductor diode.

### Construction:

- Photovoltaic cells, are made of semi-conductor diode.
- The diode has two electrical contact. A grid metal contact to facilitate light to pass through the PV cells is used on top of side and a layer metal contact on bottom side. Layer metal is usually made up of silver.
- The metal grid permits the light to fall on the diode between the grid lines.
- An antireflective coat ( $\text{Si}_3\text{N}_4$  or  $\text{TiO}_2$ ) is used between the grid lines to increase the efficiency by of light absorbance or energy conversion.

2.5M

### Working:

- When electromagnetic radiation having energy sufficient to overcome the barrier potential falls normal to the surface of the p-n junction, electron-hole pairs are formed.
- The electrons move towards the n-region
- Holes move towards the p-region.
- When an appliance or battery is connected between two contacts, circuit is completed. & electrons are driven into external circuit enabling the functioning of the appliances or charging of the battery. Charged battery is used for application such as lighting and telecommunication.

2.5M



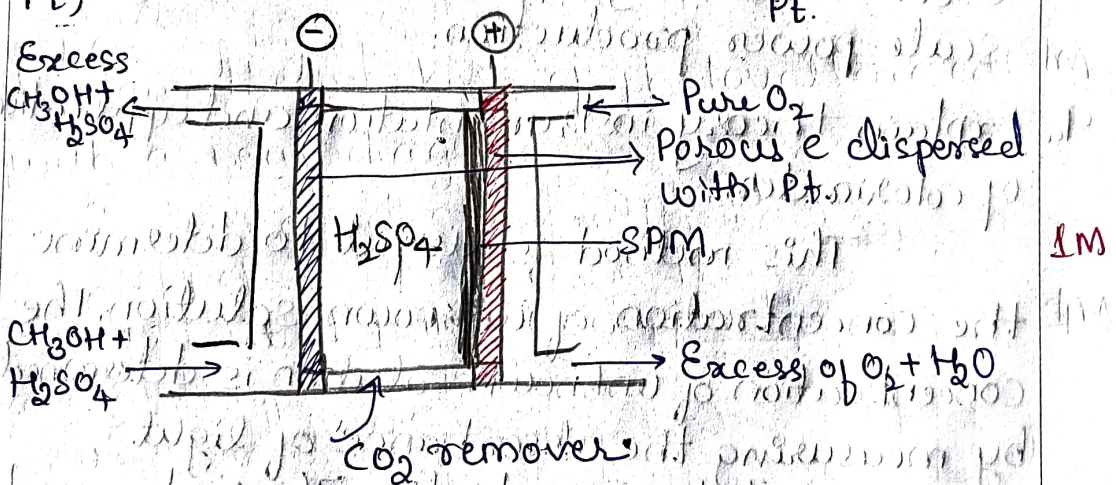
→ Depending on the energy requirement PV cells are connected either in series or parallel and designed to make modules, or panels or arrays.

8c Describe working of methyl alcohol-oxygen fuel cell  $[CH_3-OH-O_2]$  with a neat diagram. Mention its applications. 7M

Construction

The fuel is represented as \_\_\_\_\_

Porous C  
(dispersed with,  $CH_3OH-H_2SO_4$  /  $H_2SO_4(aq)$  /  $O_2$ , porous C dispersed with Pt. 2M



The cell consists of Anode & cathode: porous carbon dispersed with Pt. 1M

Electrolyte: Aqueous  $H_2SO_4$  3M

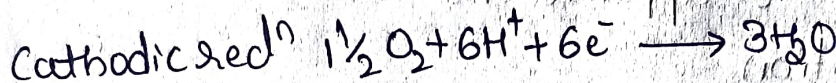
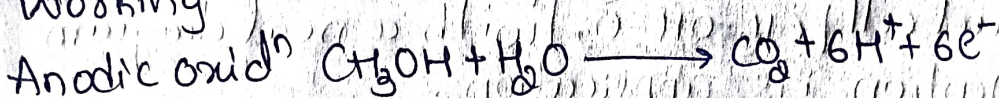
Active components:

Fuel: Methanol mixed with sulphuric acid supplied at anode

Oxidant: Pure oxygen, supplied at cathode

Adjacent to cathode, towards the electrolyte side, a semi permeable membrane is inserted to allow the diffusion of  $H^+$  ions but disallow the diffusion of methanol to avoid methanol oxidation directly at cathode.

Working



Cell potential : 1.2V

Applications:

Used in military applications & large scale power production.

9a Explain theory, instrumentation and application of colorimeter 7M

This method is useful to determine the concentration of unknown solution. The concentration of unknown solution is determined by measuring the absorbance of light with respect to concentration. The instrument name is colorimeter.

Theory:

Theory of the colorimeter is explained by Beer Lambert's law. When a monochromatic light is passed through a solution, a part of light is absorbed by the solution. The absorbance depends on the concentration of the solution and the path length of the light through the solution.

## Beer/Lambert's law

Absorbance is directly proportional to concentration and thickness.

$$A = \epsilon ct$$

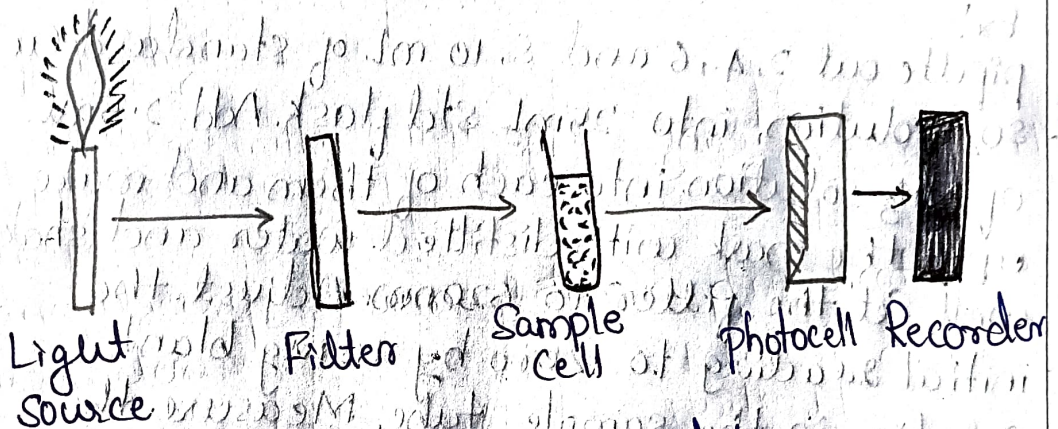
$\epsilon$  = molar absorptivity constant,

$A$  = Absorbance of light

$t$  = path length

$C$  = concentration of the solution.

## Instrumentation:



The instrument is used to measure the absorbance of a solution is called colorimeter. It consists of source: tungsten bulb or lamp is used as a light source

Filter: It is a device to provide desired wavelength range

Sample cell: Sample is hold in glass cell.

photo cell: Converts the emitted light into electrical signal.

When light is allowed to fall on the sample cell at particular wavelength. The blank solution is taken in the sample cell and placed in the path of light beam. Its absorbance

2M

is adjusted to zero. Then the analyte solution is placed in path of light and its absorbance is measured. A plot of absorbance against standard concentrations of analyte is used to find the unknown concentration of analyte in the samples.

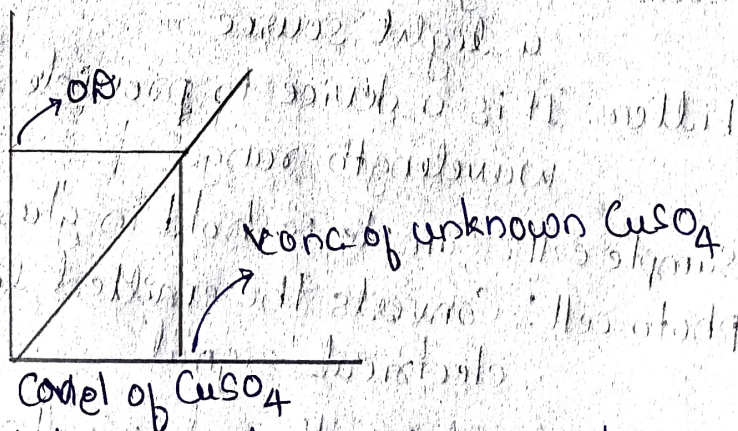
Applications.

Determination of composition of colored complex or concentration of colored complex

Ex:

pipette out 2, 4, 6 and 8, 10 mL of standard  $\text{CuSO}_4$  solution into 25 mL std flask. Add 2.5 mL of  $\text{NH}_3$  solution into each of them and make up to the mark with distilled water and shake well. Set the filter to 620 nm. Adjust the initial reading to zero by using blank solution in the sample tube. Measure the absorbance for each standard flask solution and plot graph of absorbance vs concentration of  $\text{CuSO}_4$ .

2M



- 2) In quantitative analysis, large numbers of metal ions, anions and cations compounds can be determined.
- 3) photometric titration also it is used.

96 Explain the principle of volumetric analysis and requirement of volumetric analysis

6M

Principle of titrimetric/volumetric analysis

The reagent of unknown concentration reacts with a chemical of known concentration in the presence of an indicator to show the endpoint of a reaction. Volume of the reagents consumed is measured and the concentration of analyte is calculated using the formula:

$$N_1 V_1 = N_2 V_2$$

where  $N_1$  &  $N_2$  are the normality of titrant and titrand respectively.  $V_1$  and  $V_2$  are the volumes of titrant & titrand respectively.

1M

Requirement of titrimetric analysis

→ The analyte must react completely and rapidly with the other reagent in stoichiometric proportion.

→ There must be an alteration in the physical or chemical property of the solution at the equivalence point, which can be detected by an indicator or by measuring the potential difference or current etc.

3M

Standard solution: A solution of known concentration is called as std soln.

Primary standard:

Any compound in which total amount of impurities does not exceed 0.01 to 0.02% is considered as primary standards.

Conditions for primary standard

- Easily available in pure and dry form
- Safely stored
- Easy to detect the impurities present in it
- Should give high relative molecular mass
- Readily soluble in a suitable solvent.

Requirements of primary standard solution

- Has a high level of purity
- Has low reactivity
- Has a high equivalent weight
- Is not likely to absorb moisture from the air to reduce changes in mass in humid v/s dry environments.
- Is non toxic

2M

Secondary standard.

It is used for standardization after finding its exact concentration by titration against a std soln of primary standard.

- 9c. Define biological oxygen demand and chemical oxygen demand. 25ml of waste water required 18.0ml and 25.2ml of 0.1N FAS solution for sample and blank titration, respectively. Calculate COD of waste water sample

7M

Biological oxygen demand

It is the number of milligrams of oxygen required by microorganisms to oxidize the organic matter in a water sample over a period of 5 days under aerobic condition at 20°C.

1M

Chemical oxygen demand.

It is the number of milligrams of oxygen required for the complete oxidation of both organic & inorganic matter present in 1L of wastewater, using strong oxidizing agent.

1M

$$Z = 25 \text{ mL}$$

$$\text{Main titre value} = 18.0 \text{ mL (P)}$$

$$\text{Blank titre value} = 25.2 \text{ mL (Q)}$$

$$\text{Normality of FAS} = 0.1 \text{ N (Y)}$$

$$(Q-P) = 25.2 - 18.0$$

$$= 05.2 \text{ mL}$$

$$\text{COA} = \frac{8}{1000} \times (Q-P) \times Y \times \frac{10^6}{Z}$$

$$= \frac{8}{1000} \times 5.2 \times 0.1 \times \frac{10^6}{25}$$

$$= \frac{0.1664 \times 10^6}{1000}$$

$$= 0.1664 \times 10^3$$

$$= 166.6 \text{ ppm.}$$

4M

1M

10a Explain applications of conductometry

7M

i. Strong acid vs strong base

ii. Weak acid vs strong base

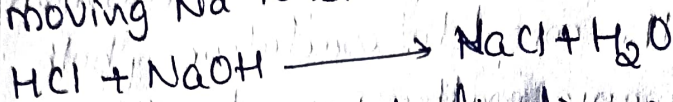
Strong acid vs strong base

HCl vs NaOH

If the strong acid like HCl is titrated against a strong base such as NaOH, the conductance first decreases, due to

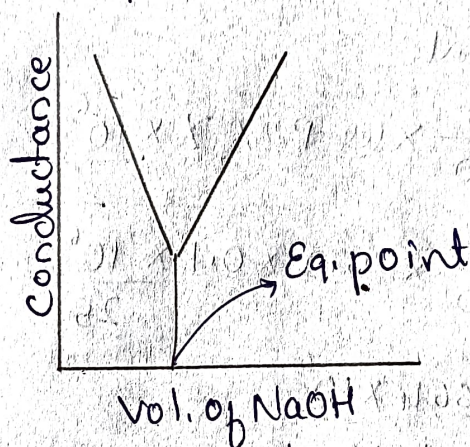
Q.No.

replacement of fast moving  $H^+$  ions by slow moving  $Na^+$  ions.



After the neutralisation point, conductivity rapidly rises with further addition of NaOH because of continuous addition of fast moving  $OH^-$  ions.

A plot of conductance against the volume of base added is shown below. The point of intersection of two curves gives the neutralisation point.



3M

Weak acid vs strong base

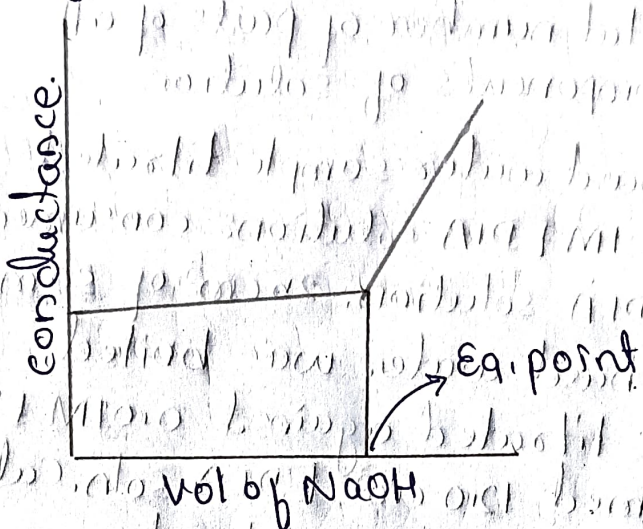
Consider the titration of acetic acid against NaOH. The conductance of acid will be initially low since acetic acid is a weak electrolyte. When the NaOH is added to the acid, the salt formed is highly ionized and the conductance increases.

On complete neutralisation of the acid further addition of base leads to an increase in the number of mobile  $OH^-$  ions. Hence the conductance increases sharply.





A plot of conductance against the volume of base added is shown in the figure. The point of intersection of two curves gives the neutralisation point.



3M

10b Define the following units of standard soln.  
 i) Normality ii) Molarity iii) ppm

6M

**Normality**

It is the number of gram equivalent of solute dissolved per litre of solution. It is denoted by 'N'.

$$N = \frac{\text{No. of equivalents of solute}}{\text{vol of the solution}}$$

2M

**Molarity**

It is the number of moles of the solute dissolved per litres of the solution. It is denoted by M

$$M = \frac{\text{Mass of solute}}{\text{vol of solution in litres}}$$

2M

ppm

A part per million is one part of solute per million parts of the solution.

$$\text{ppm} = \frac{\text{No. of parts of component}}{\text{Total number of parts of all components of solution}} \times 10^6 \quad 2M$$

10c. 25 cm<sup>3</sup> of hard water sample titrated against 0.01M EDTA solutions consumed 18 cm<sup>3</sup> of EDTA solution. 25 cm<sup>3</sup> of same sample of hard water was boiled, filtered & titrated against 0.01M EDTA soln consumed 12.0 cm<sup>3</sup> EDTA soln. Calculate Total hardness, permanent hardness & Temporary hardness of the water sample. 7M

Total hardness calculation

$$Z = 25 \text{ cm}^3$$

$$P = 18 \text{ cm}^3$$

$$Y = 0.01 \text{ M}$$

$$\text{Total hardness} = \frac{100}{1000} \times P \times Y \times \frac{10^6}{Z}$$

$$= 0.1 \times 18 \times 0.01 \times \frac{10^6}{25}$$

$$= 1.2 \times 10^4 \times 10^6$$

$$= 720 \text{ ppm} \quad 3M$$

Permanent hardness calculation

$$Z = 25 \text{ cm}^3$$

$$Q = 12 \text{ cm}^3$$

$$Y = 0.01 \text{ M}$$

$$\begin{aligned} \text{Permanent hardness} &= \frac{0.1 \times Q \times Y \times 10^6}{2} \\ &= \frac{0.1 \times 12 \times 0.01 \times 10^6}{25} \\ &= 4.8 \times 10^{-4} \times 10^6 \\ &= 480 \text{ ppm} \end{aligned}$$

Temporary hardness calculation

$$\begin{aligned} \text{Temporary hardness} &= \text{Total hardness} - \text{Permanent hardness} \\ &= 720 \text{ ppm} - 480 \text{ ppm} \\ &= 240 \text{ ppm.} \end{aligned}$$

Staff in charge!

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Group  
Dean academics

3M

1M