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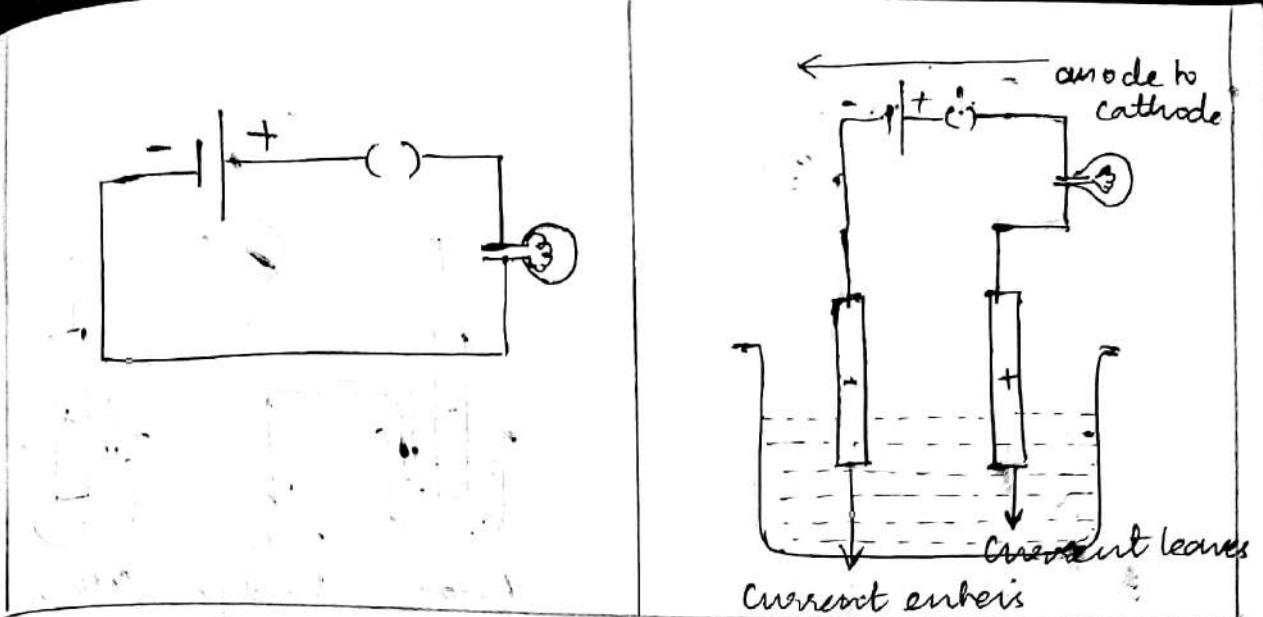
Electrochemistry

- * It is a collective name for chemical effects of electricity. It is defined as the study of solution of an electrolyte and the phenomenon occurring at electrodes which are immersed in electrolyte.
- * Based on the ability of material to allow current to pass through it, materials are broadly classified into three types : conductors, semiconductors and insulators.
- * Conductors allow current to pass through it.
- * Semiconductors allow current to pass through it with difficulty.
- * Insulators ~~allow~~ does not allow current to pass through it.

* conductors

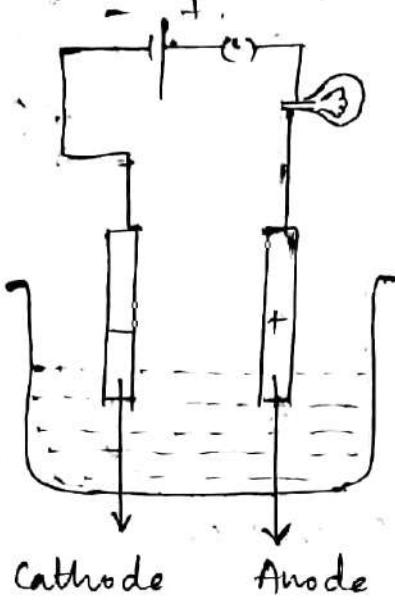
- Metallic conductors (Or) Electronic conductors
- Electrolytic conductors (Or) Electrolytes

METALLIC	ELECTROLYTIC
<ul style="list-style-type: none">• electrons are charge carriers.• they have -ve temp. coefficient of conductors• No. of charge carriers are same irrespective of the material used.• they conduct electricity in solid as well as liquid state.• Ex: All metals	<ul style="list-style-type: none">• ions are charge carriers.• They have +ve temp. coefficient of conductors• No. of charges per charge carrier need not be same and it depends upon valency of the ion.• they conduct electricity in fused state (Or) in solution (Or) liquid form. only• ex: Solutions of acids, bases and salts.

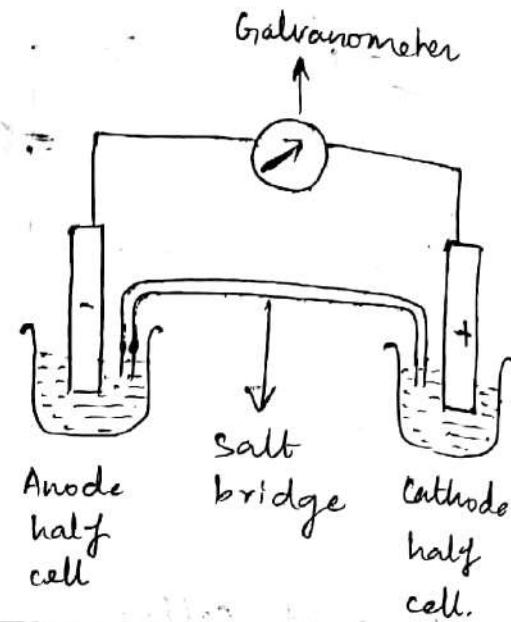


→ Types of Cells:

ELECTROLYTIC	GALVANIC
<ul style="list-style-type: none"> It converts electrical energy to chemical energy. Anode is +vely charged. cathode is -vely charged. Salt bridge is not required to complete the circuit. Chemical reactions takes place when electricity is passed through the electrolyte. Ions are discharged at both the electrodes 	<ul style="list-style-type: none"> It converts chemical energy to electrical energy. Anode is -vely charged. cathode is +vely charged. Salt bridge is required to complete the circuit. Current is produced due to spontaneous chemical reactions. Ions are discharged only on cathode.



Ex: Ni bath, Cr bath



Ex: Daniell cell

1 - Resistance - The obstruction followed by a conductor for the flow of current through it.

Units: ohm.

The conductor which has resistance is called a resistor.

Resistor is a component which resists the flow of current.

It is made up of a metal wire or a carbon rod.

It is used to control the current in a circuit.

It is also used to protect the circuit from short circuiting.

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2 - conductance - It is a measure of

the ease with which the conductor

allows current to pass through it . It is

denoted by C . Units: ohm $^{-1}$, mho, Ω^{-1}

siemens.

$$\left[C = \frac{I}{R} \right]$$

3 - specific resistance - The R offered by a conductor of unit length and unit area of cross-section denoted by ρ :

$$\left[\rho = \frac{Ra}{l} \right] \quad \text{units: ohm-cm (or)} \\ \text{ohmm.}$$

4 - specific conductance - It is the C offered by the solution taken in b/w two electrodes which are 1 cm apart and has unit area of cross section (or) it is conductance offered by unit volume of solution (C_{cc}) . Denoted by K .

$$\left[K = \frac{C}{\rho} = \frac{1}{\rho} \frac{l}{a} \right] \quad \text{ohm}^{-1} \text{cm}^{-1}$$

Factors effecting rate of conductance (or) Conductivity

→ Nature of electrolyte

→ Number of ions

→ Temperature

→ Ionic mobility.

$$\left[\frac{l}{a} = \text{cell constant} \right]$$
$$= \kappa \times (\text{cm}^{-1})$$

If concentration of electrolyte increases, the conductance increases.

Upon dilution, specific conductance decreases.

5 - Equivalent conductivity (λ_{eq})

$$\lambda_v = \frac{1000 K}{c}$$

$$V = \frac{1000}{c} \text{ in lit.}$$

$$\Rightarrow \boxed{\lambda_v = KV} \cdot \text{ ohm}^{-1} \text{ cm}^2 \text{ equiv}^{-1}$$

It is conductance offered by solution when

1 gm equivalent wt. of an electrolyte is dissolved in 1 lit of solvent / solution.

6 - Molar conductivity [λ_m]

It is the C offered by solution when 1 gm

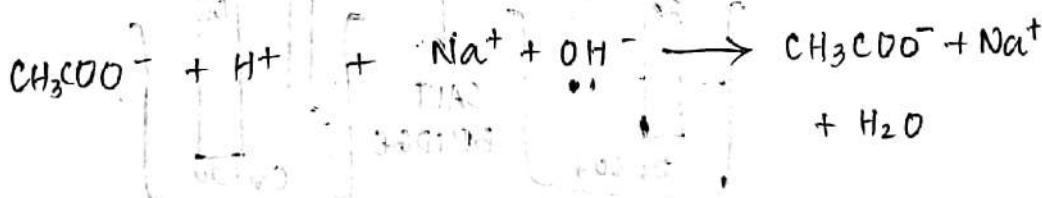
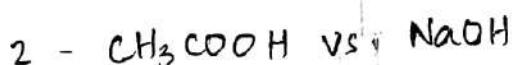
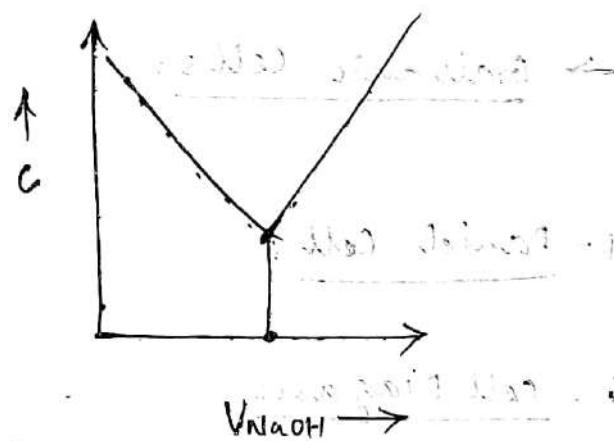
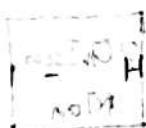
mol. wt. of electrolyte is dissolved in 1 lit.
of solvent / solution

$$\lambda_m = \frac{1000K}{c}$$

$$V = \frac{1000}{c} \text{ in lit.}$$

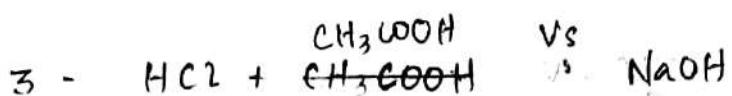
$$[\lambda_m = KV] \text{ ohm}^{-1} \text{cm}^2 \text{mol}^{-1}$$

→ Determination of amount of Acid present in
a given test solution by measuring con-
ductivity:



The C increases, as V(NaOH) due to the presence of
Na⁺ which causes higher ionic mobility. As we go

on increasing the $V(NaOH)$, the C increases abruptly.

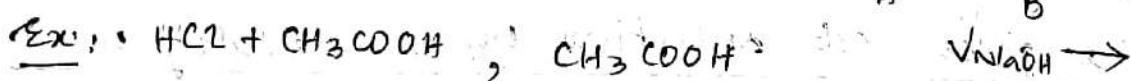
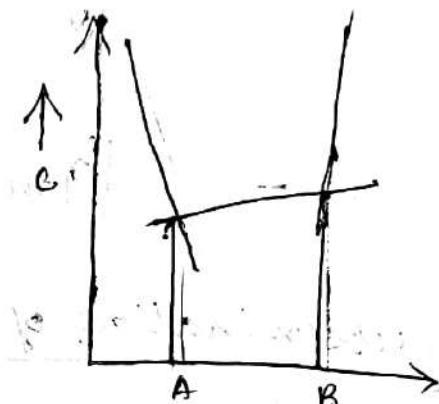


Principle - common ion effect

suppression of dissociation of

weak acid when there

are common ions.



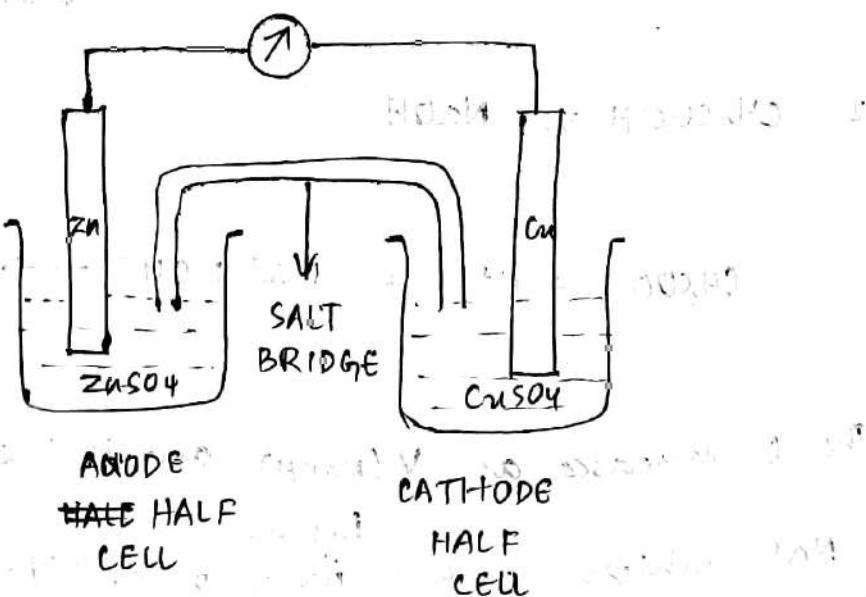
will not dissociate due to common H^+ ions

→ Galvanic cells:

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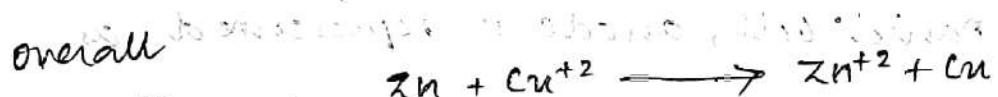
i - Daniel Cell

i - cell Diagram,

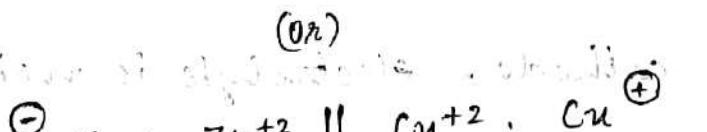
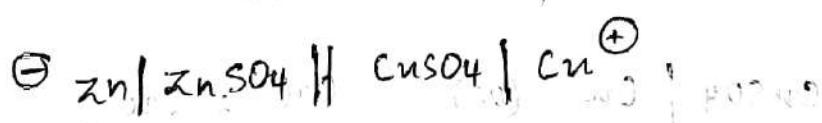


ii - cell description - In Daniell cell, Zn plate dipped in ZnSO_4 acts as anode; so Cu plate dipped in CuSO_4 acts as cathode. Anode undergoes oxidation reaction and cathode undergoes reduction reaction. Anode is given -ve sign and cathode is given +ve sign. Both the half cells are connected by salt bridge.

iii - cell reactions:



iv - Cell notation:



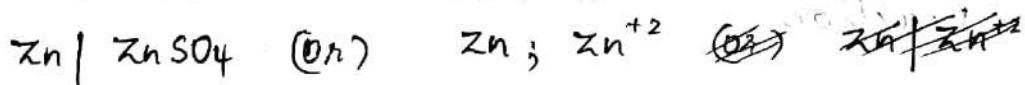
v - Cell of Daniell cell: [EMF]

$$E_{\text{cell}} = 1.1 \text{ V}$$

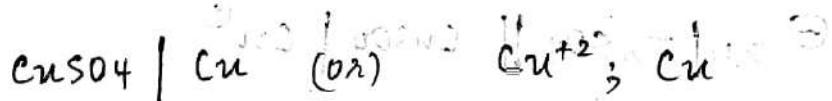
→ Cell representation (or) Cell notation:

- Any given Galvanic cell can be represented by following the rules given by IUPAC:
- 1 - Anode should be always represented at on left hand side and cathode on Right hand side.
 - 2 - To represent anode, electrode is written first followed by electrolyte, both are separated by a vertical line (or) semicolon. Electrolyte maybe written as a whole or in a form of ions.

Ex: In Daniell cell, anode is represented as



cathode is represented as



- 3 - To represent cathode, electrolyte is written first followed by electrode, both are separated by vertical line (or) semicolon. Electrolyte maybe written in the form of ions.

4- Bott are salt bridge is represented by two vertical lines "||".

Ex: Daniel cell is represented as :



* Role of Salt Bridge: It is an inverted U-shaped glass tube filled with KCl | NH₄NO₃ in agar-agar gel.

- 1- It prevents intermixing of two half cell solutions.
- 2- It is permeable to only ions.
- 3- It maintains electrical neutrality.
- 4- It completes the circuit.
- 5- It prevents liquid junction potential
[Accumulation of charges]

→ Electrode Potential: It is the tendency

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of an electrode to lose or gain electrons.

→ Standard Electrode Potential - Electrode

potential measured at 25°C, unit concentration and 1 atmospheric pressure.

→ single electrode Potential - It is potential

developed when electrode is in contact with its own ions. (${}^{\circ}\text{C}$)

- We cannot measure single electrode potential.
- To measure SEP, electrode has to be connected to another half cell whose potential is known.
- The electrode which is connected to another half cell and whose potential is known is called reference electrode.

Ex: Standard Hydrogen Electrode (SHE)

• $\boxed{\text{SRP} = 0.00\text{V}}$

→ Standard Oxidation Potential - The tendency of electrode to lose e^- s at 25°C , unit concentration and 1 atm.

→ Standard Reduction Potential - The tendency of electrode to gain e^- s at 25°C , unit concentration and 1 atm.

- SOP is the reversal of SRP and vice versa.

Ex: SOP of Zn electrode is +0.76 V.

SRP of Zn electrode is -0.76 V.

→ Electrode Potential is denoted by E and units is V.

- By following IUPAC rules, SRP values of an electrode are given in description of Galvanic cell.

→ EMF of a cell (E_{cell}) - The difference in potential which causes current to flow from electrode of higher potential to lower potential is known as E_{cell} .

$$[E_{cell} = E_{cathode} - E_{anode}]$$

- If E_{cell} is +ve, the cell is said to be feasible.
- If E_{cell} is -ve, the cell is not feasible and electrodes have to be reversed (or) interchanged.

→ Cell reaction is written in the following way:

Reduction half-reaction

+ Oxidation half-reaction

* Derivation of Nernst equation:

In 1889, scientist Nernst derived a quantitative relation between electrode potential and concentration of electrolytes.



By convention, reduction reaction is written

because reduction potentials are considered to explain a Galvanic cell.

Changing free energy for the above reaction ΔG

is given by ~~as~~ a well known thermodynamic equation, i.e.,

$$\Delta G = \Delta G^\circ + RT \ln K \quad \text{--- (1)}$$

where ΔG° = standard free energy change.

~~Gas constant~~ R = Gas constant

T = Absolute temperature

K = Reaction coefficient of activities of products and reactions.

The above equation can be written as

$$\Delta G = \Delta G^\circ + RT \ln \left[\frac{am}{am^{n+}} \right] \quad \text{--- (2)}$$

substituting molar concentrations in place of activities,

$$\Delta G_i = \Delta G^\circ + RT \ln \frac{[m]}{[m^{n+}]} \quad \text{--- (3)}$$

if 'n' is the no. of e's transferred and 'E' is electrode potential, the work done due to above reaction is given by ' $-nFE^\circ$ ' (or)

$$\Delta G = -nFE^\circ \quad \text{and} \quad \Delta G^\circ = -nFE^\circ \quad \text{--- (4)}$$

substituting (4) in (3), we get

$$-nFE^\circ = -nFE^\circ + RT \ln \frac{[m]}{[m^{n+}]} \quad \text{(canceling)}$$

Divide both the sides with ' $-nF$ '

$$E = E^\circ - \frac{RT}{nF} \ln \frac{[m]}{[m^{n+}]} \quad \text{(6r)}$$

$$\Rightarrow E = E^\circ - \frac{2.303 RT}{nF} \log \frac{[m]}{[m^{n+}]} \quad \text{(6r)}$$

where E = Electrode Potential, F = Faraday = 96500C

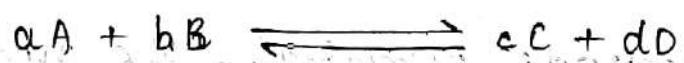
E° = Standard Electrode Potential

R = Gas constant, T = Absolute Temp.

substituting the values of $R = \frac{8.314 J}{K \cdot mol}$ and $T = 298 K$

$$\Rightarrow \left[\epsilon = \epsilon^\circ - \frac{0.0591}{n} \log \frac{[m]}{[m^{n+}]} \right]$$

Nernst equation also gives relationship between ϵ_{cell} and concentration of electrolyte.



For the above reaction,

$$\left[\epsilon_{cell} = \epsilon_{cell}^\circ - \frac{2.303RT}{nF} \log \frac{[C]^c [D]^d}{[A]^a [B]^b} \right]$$

(ON)

At $25^\circ C$,

$$\left[\epsilon_{cell} = \epsilon_{cell}^\circ - \frac{0.0591}{n} \log \frac{[C]^c [D]^d}{[A]^a [B]^b} \right]$$

$$\text{Activity of } m = 1 \Rightarrow \left[\epsilon = \epsilon^\circ - \frac{0.0591}{n} \log \frac{1}{[m^{n+}]} \right]$$

Applications of Nernst equation:

1 - It gives the relationship between electrode potential and concentration of an electrolyte.

2 - Electrode potential of a half cell can be determined under non standard condition.

3 - pH of the solution can be determined as electrode potential is related to pH.

- 4 - No. of e⁻'s transferred during a reaction can be determined.
- 5 - If concentration of any one electrolytic species is not known, it can be determined provided the values of the other terms.

→ Types of Electrodes:

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1 - Metal - metal ion electrode.

2 - Gas - ion electrode.

3 - Metal - metal insoluble electrode.

4 - Redox electrode.

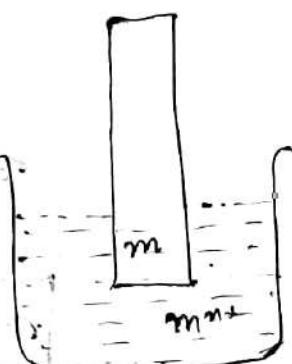
5 - Metal - metal Amalgam electrode.

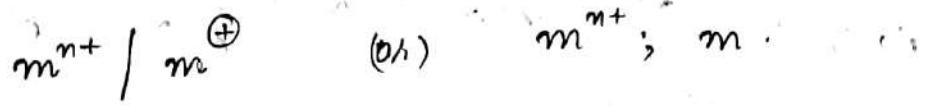
1 - Metal - metal ion electrode

- Metal ^m in contact with its own ions M^{n+}
becomes metal-metal ion electrode.

e.g.: Half cells of Daniell Cell.

- Electrode reaction





- Equation: $E = E^\circ - \frac{2.303 RT}{nF} \log \frac{[m]}{[m^{n+}]}$

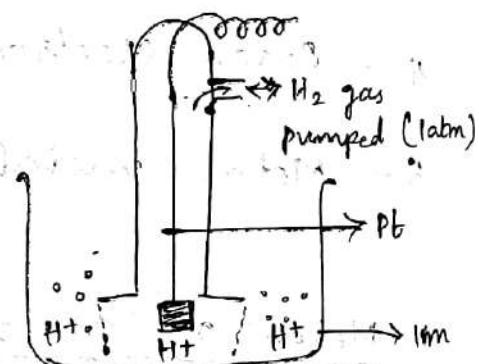
2- Gas ion electrode:

An inert metal dipped in a solution having ions reversible to the gas continuously pumped into the electrode / cell becomes gas ion electrode.

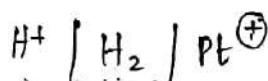
→ standard Hydrogen electrode (SHE)

Electrode

Reaction:



Cell Notation:



Equation:

$$E = E^\circ - \frac{0.0591}{1} \log \frac{1}{[H^+]}$$

(or)

$$E = -0.0591 \log \frac{1}{[H^+]}$$

$$E = \pm 0.059 \text{ pH}$$

13 - Metal - metal Insoluble Electrode

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Description. - It consists of metal, sparingly soluble salt of the same metal, and an electrolytic solution having same anions ~~say~~ as that of sparingly soluble salt.

An inert electrode like Pt wire is used for electrical contact. Ex: Calomel Electrode

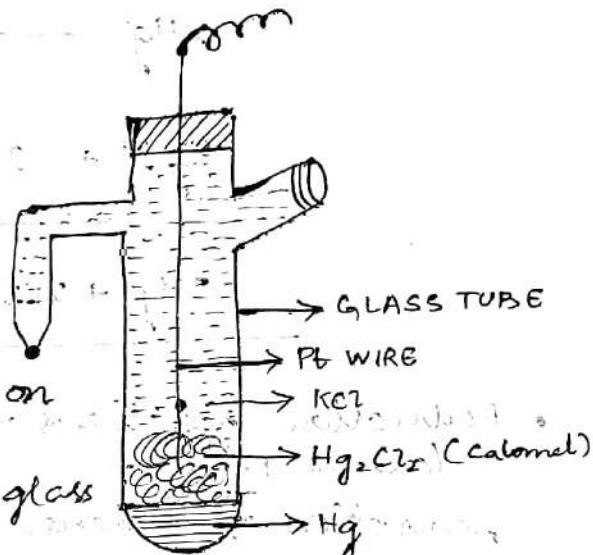
→ Calomel Electrode :

(Hg_2Cl_2 - common name):

Description - It consists of

glass tube with side tubes on

either sides. Bottom of the glass



tube is filled with Hg. Hg is covered by sparingly soluble salt Hg_2Cl_2 . Complete tube is filled

with KCl solution. Pt wire is used for electrical contact. Side tube on right side is used for

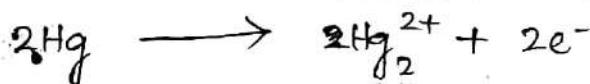
filling KCl solution. Side tube on left side is

used for connecting this electrode to other half cell.

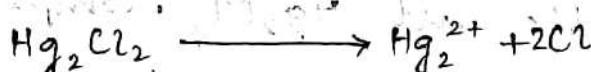
calomel electrode can undergo oxidation (Ox)
reduction reactions depending upon the nature
of other half cell to which it is connected

Electrode Reactions:

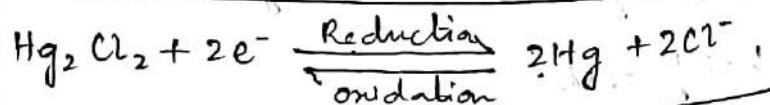
- Oxidation reactions - When calomel electrode (Anodic Reactions) undergoes oxidation reactions, decrease in Cl^- concentration of Cl^- ions in electrolyte is observed



- Reduction reactions - When electrode undergoes (Cathodic Reactions) reduction reactions, increase in concentration of Cl^- ions is observed



Oxidation and Reduction reactions (redox) can be written as

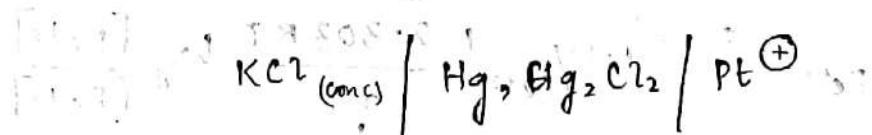
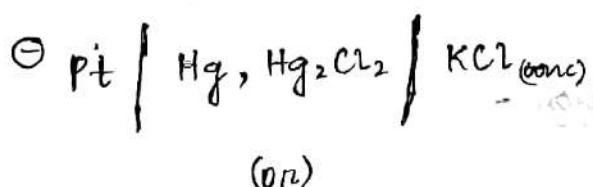


Therefore, calomel electrode is said to be the reversible to Cl^- ions.

SRP of calomel electrode depends upon concentration of KCl used. Therefore, a given calomel electrode can be of DNCE [Deci Normal calomel electrode] - 0.1N KCl (or) NCE [Normal calomel electrode] - 1N KCl (or) [SCE [saturated calomel electrode]] - Saturated see [saturated calomel electrode]

TYPE OF CALOMEL ELECTRODE	CONCENTRATION OF KCl	SRP
DNCE	0.1N	0.3335V
NCE	1N	0.2810V
SCE	SATURATED	0.2422V

Electrode Notation:



4- Redox electrode:

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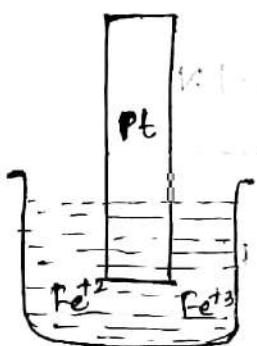
Definition - When inert electrode like Pt comes in contact with a solution

having ions of two different oxidation states, it becomes redox electrode.

Ex: Fe^{+2} , Fe^{+3} with Pt, Quinhydrone electrode.

→ Fe^{+2} , Fe^{+3} with Pt electrode:

Description - When Pt electrode comes in contact with a solution having Fe^{+2} , Fe^{+3} ions, it becomes this redox electrode.



Electrode Reactions - $2\text{Fe}^{+3} + 2e^- \rightleftharpoons 2\text{Fe}^{+2}$

Electrode notation - $\text{Fe}^{+3}, \text{Fe}^{+2} / \text{Pt}$

Electrode equation -

$$\text{E}_{\text{Fe}^{+3}/\text{Fe}^{+2}} = \text{E}^\circ_{\text{Fe}^{+3}/\text{Fe}^{+2}} + \frac{2 \cdot 303 \text{ RT}}{nF} \log \frac{[\text{Fe}^{+3}]}{[\text{Fe}^{+2}]}$$

(1)

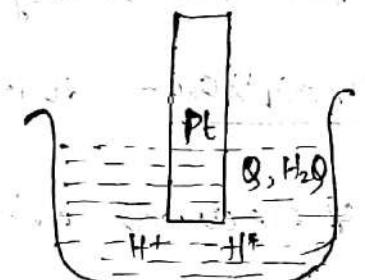
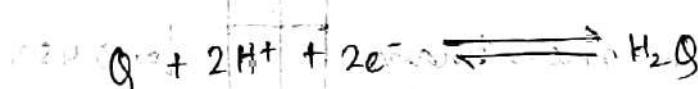
Quinhydrone electrode:

Description: When Pt electrode comes in contact with acid solution (H^+ ions) and a sparingly soluble (1:1) equimolar mixture of Quinone and Hydroquinone (black powder) i.e.,

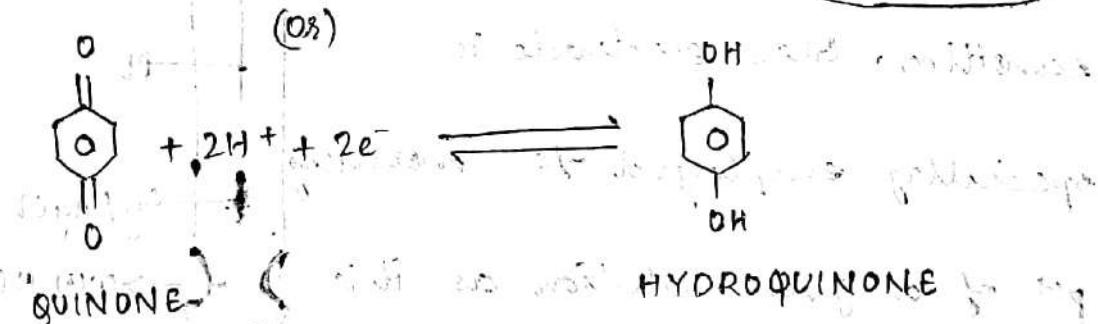
Quinhydrone powder, it becomes

Quinhydrone electrode

Electrode Reactions:



(O3)



Electrode Notation - $\text{H}^+ \text{ (unknown)} \mid Q, H_2Q \mid \text{Pt}^\oplus$

Electrode equation -

$$\epsilon_{QE} = \epsilon_{QE}^\circ - \frac{0.0591}{2} \log \frac{1}{[H^+]^2}$$

$$\epsilon_{QE} = \epsilon_{QE}^\circ - 2 \times \frac{0.0591}{2} \log \frac{1}{[H^+]^2} \quad [\epsilon_{QE}^\circ = 0.6996 \text{ V}]$$

$$\boxed{\epsilon_{QE} = 0.6996 - 0.0591 \text{ pH}}$$

→ ~~Potentiometric Titrations~~

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b) Determination of amount of HCl present in given test. solution using SCE and GE.

Refer manual (lab) for this ~~manual~~ answer.

**** → Glass electrode [Membrane sensitive electrode].

[Quinhydrone powder is not stable beyond pH 8, that's why Glass electrode is more preferred than GE for measuring pH of solution]

Description - It is a special type

of electrode which is membrane

sensitive. Glass electrode is

specially employed for measuring

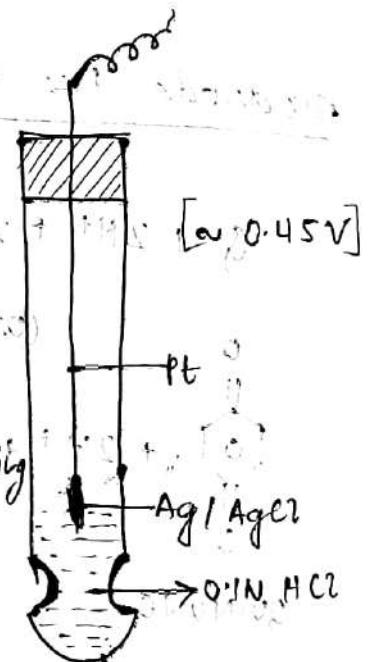
pH of a given solution as it is

pH-sensitive. This electrode consists of a glass bulb which is made up of a special

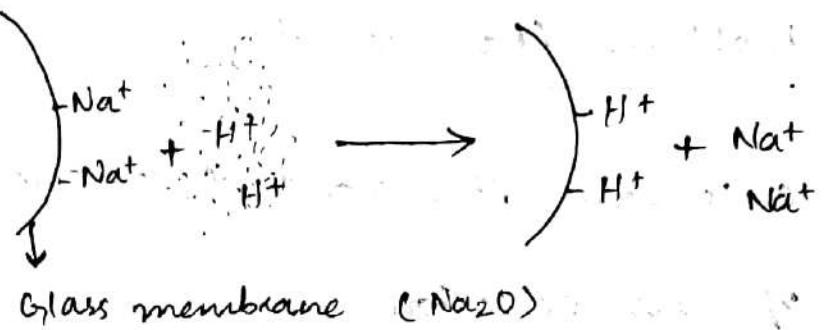
type of glass known as Corning glass. It acts

as ion exchange resin as Na^+ of glass ion can

be exchanged with H^+ ions present in the



solution.

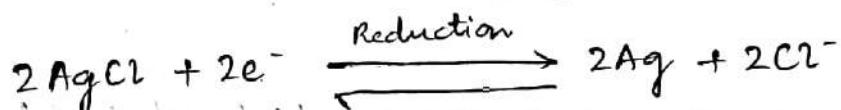


Glass bulb is filled with 0.1N HCl Pt wire
Ag/ with AgCl dip tip serves as electrical contact.

Glass bulb is fused to normal / regular glass tube. When this is dipped in Acid of different concentration, due to difference in H^+ ions on membrane and solution, difference in potential arises. As potential is related to pH, this electrode is used for measuring pH of given

solution.

Electrode Reactions:



Reduction half cell : $\text{Ag} + \text{Cl}^- \rightarrow \text{AgCl} + e^-$
Oxidation half cell : $\text{Ag} + \text{H}^+ + \text{Cl}^- \rightarrow \text{AgCl} + \frac{1}{2}\text{H}_2\text{O}$

Equation:

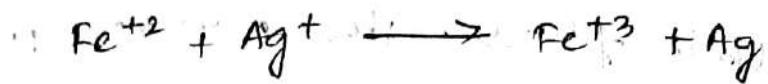
$$\text{V}_{\text{inj. Regass}} = E_{\text{glass}}^{\circ} - 0.059 \log \text{pH.}$$

Notation:

glass membrane | 0.1N HCl | Ag, AgCl / Pt⁺

→ Problems (Numericals)

Q1) calculate standard free energy change of cell reaction



given

$$\epsilon^\circ_{\text{Ag}^+/\text{Ag}} = 0.80 \text{ V}$$

$$\epsilon^\circ_{\text{Fe}^{+3}/\text{Fe}^{+2}} = 0.77 \text{ V}$$

Sol) $\Delta F^\circ \epsilon^\circ = \epsilon^\circ_{\text{cathode}} - \epsilon^\circ_{\text{anode}}$

$$0.80 - 0.77$$

$$\epsilon^\circ = 0.03$$

$$\Delta G^\circ = -nF\epsilon^\circ$$

$$= -1 \times 96500 \times 0.03$$

$$\boxed{\Delta G^\circ = -2895 \text{ J}}$$

Q2) What is the potential of half cell consisting of Zn electrode in 0.01M ZnSO₄ solution at 25°C.

Given $E^\circ_{Zn^{+2}/Zn} = -0.76V$

$$E^\circ_{Zn^{+2}/Zn} = -0.76V$$



$$\epsilon = E^\circ - \frac{0.0591 \log(0.01)}{n}$$

(a)

$$\epsilon = -0.76 - \frac{0.0591 \log(\frac{1}{0.01})}{2}$$

$$\epsilon = -0.76 + 0.0591$$

~~$\epsilon = -0.7009V$~~

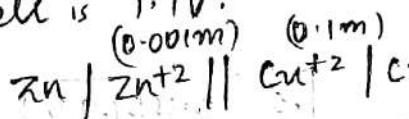
$\epsilon = -0.8191V$

(b) Calculate the EMF of a Daniel Cell at 25°C

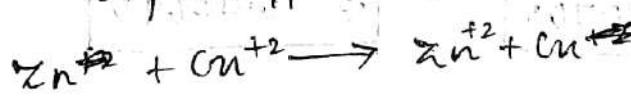
when concentration of $ZnSO_4$ and $CuSO_4$

are 0.001M and 0.1M. Standard Potential

of the cell is 1.1V.



(a)



$$\epsilon_{cell} = E^\circ_{cell} + \frac{0.0591}{n} \log \frac{[Cu^{+2}]}{[Zn^{+2}]}$$

and $E^\circ_{cell} = 1.1 + 0.0591 \log \frac{0.1}{0.001}$

$$\epsilon_{cell} = 1.1 + \frac{0.0591}{2} \log \frac{0.1}{0.001}$$

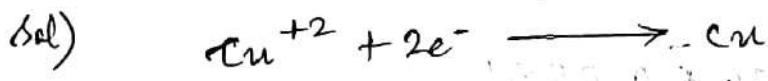
Applying the condition \downarrow

$$\epsilon_{cell} = 1.1 + 0.0591 \times 0.3010$$

$$[\epsilon_{cell} = 1.0409 \text{ to } 1.1591V]$$

Q4) Calculate electrode potential of Cu electrode which is in contact with a solution of $4 \times 10^{-5} \text{ m}$ Cu^{+2} ions at 25°C .

SRP of $\text{Cu}^{+2}/\text{Cu} = 0.337 \text{ V}$



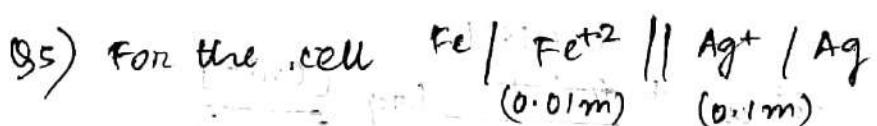
$$\epsilon_{\text{cell}} = \epsilon^\circ + \frac{0.0591}{2} \log \frac{1}{[\text{Cu}^{+2}]}$$

$$\epsilon = \epsilon^\circ + \frac{0.0591}{2} \log \frac{1}{4 \times 10^{-5}}$$

$$\epsilon = 0.337 + \frac{0.0591}{2} \log \frac{1}{4 \times 10^{-5}}$$

$$\boxed{\epsilon = 0.2010 \text{ V}} \quad \boxed{\epsilon = 0.4669 \text{ V}}$$

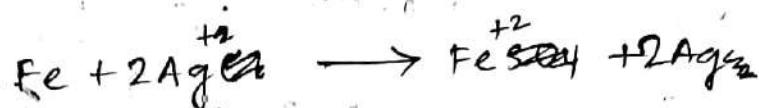
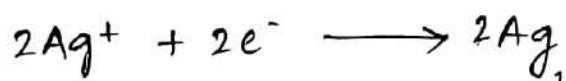
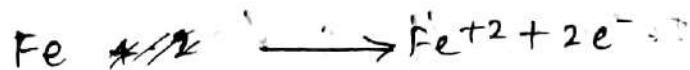
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write cell reaction. Calculate EMF of the cell at 298 K . if standard electrode potential of Fe and Ag electrodes are -0.44 V and $+0.80 \text{ V}$ respectively.

[Partial paper]

(sol)



$$\epsilon^\circ_{\text{cell}} = \epsilon^\circ_{\text{cathode}} - \epsilon^\circ_{\text{anode}}$$

$$= 0.80 - (-0.44) = 1.24 \text{ V}$$

$$\epsilon_{\text{cell}} = \left(\frac{\epsilon_{\text{cell}} - 0.0591}{2} \right) \log \frac{[\text{Fe}^{+2}]}{[\text{Ag}^+]}$$

$$\epsilon_{\text{cell}} = 1.24 - \frac{0.0591}{2} \log \left[\frac{0.01}{0.1^2} \right]$$

$$\boxed{\epsilon_{\text{cell}} = 1.24 \text{ V}}$$

Q8) What is the maximum electrical energy obtained from Daniell cell under standard conditions

$$[\epsilon^\circ_{\text{cell}} = 1.1 \text{ V}]$$

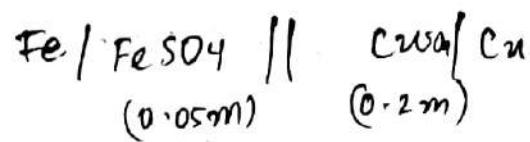
(sol)

$$\Delta G^\circ = -nFE^\circ$$

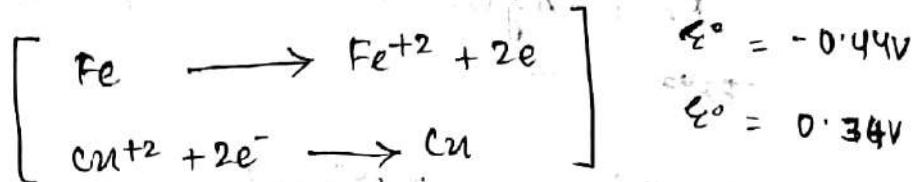
$$= -2 \times 96500 \times 1.1$$

$$[\Delta G^\circ = -212300 \text{ J}]$$

(Q7)



$$\epsilon_{\text{cell}}^{\circ} = 0.34 + 0.44 = 0.78V$$



$$\epsilon_{\text{cell}} = \epsilon_{\text{cell}}^{\circ} + \frac{0.0591}{n} \log \left[\frac{0.2}{0.05} \right]$$

$$= 0.78 + \frac{0.0591}{2} \log \left(\frac{0.2}{0.05} \right)$$

$$\boxed{\epsilon_{\text{cell}} = 0.78V}$$

(Q8) A Zn rod is dipped in ZnSO_4 . The salt is 95% dissociated at 298K. calculate electrode potential ($\epsilon_{\text{Zn}^{+2}/\text{Zn}}^{\circ} = -0.76V$)

~~by using Nernst's equation~~



$$\epsilon = -0.76 - \frac{0.0591}{2} \log \left[\frac{1}{\frac{95 \times 0.1}{100}} \right]$$

$$\boxed{\epsilon = -0.7902V}$$

(a) calculate the equilibrium constant of the reaction $\text{Cu} + 2\text{Ag}^+ \rightarrow \text{Cu}^{+2} + 2\text{Ag}$
 $[\epsilon_{\text{cell}}^\circ = 0.46\text{V}]$.

(sol) At equilibrium, ϵ_{cell} and ΔG° doesn't exist.

$$\epsilon_{\text{cell}}^\circ = \frac{0.0591}{n} \log K$$

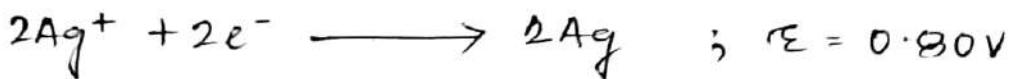
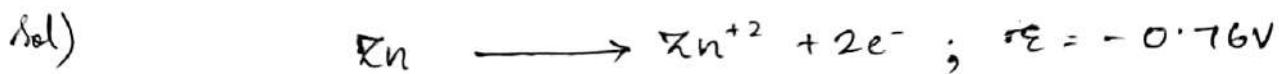
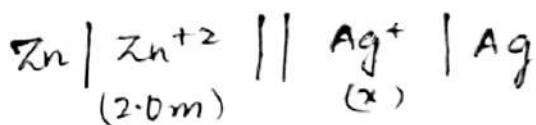
$$\frac{0.46 \times 2}{0.0591} = \log K$$

$$\left. \begin{aligned} \Delta G^\circ &= -nFE^\circ \\ \Delta G^\circ &= RT \ln K \\ E^\circ &= \frac{0.0591}{n} \log K \end{aligned} \right]$$

$$K = \text{Antilog } (5.5668) = 10^{\downarrow} \quad \begin{array}{l} \text{15.5668} \\ \downarrow \\ \Rightarrow 3.688 \times 10^{15} \end{array}$$

$$= K = 3.688 \times 10^{15}$$

(b) A voltaic cell has ϵ_{cell} value of 1.536V . what is the concentration of Ag^+ in the cell.



Q12) A H₂-electrode was combined with [1 Feb
SCE. The EMF of the combination
was 0.673 V. What is the pH of the
solution if potential of SCE is 0.248 V
at the same temperature.

Sol). Anode = H₂E

Cathode = SCE.

$$\epsilon_{\text{cell}} = \epsilon_c - \epsilon_a$$

$$0.673 = 0.248 - (-0.0591 \text{ pH})$$

$$0.673 - 0.248 = 0.0591 \text{ pH}$$

$$\text{pH} = \frac{0.673 - 0.248}{0.0591} = 7.1912$$

For, SCE and O₂:

$$\epsilon_{\text{cell}} = \epsilon_c - \epsilon_a$$

Cathode = O₂E

Anode = SCE

$$0.673 = (\epsilon^{\circ} - 0.0591 \text{ pH}) - 0.2422$$

$$\underline{0.673 - 0.6996 + 0.2422 = 0.0591 \text{ pH}}$$

$$0.2422 + 0.673 = (0.6996 - 0.0591 \text{ pH})$$

$$\underline{0.9152 - 0.6996 = \text{pH} = 3.6480}$$

→ Battery:

- A battery is a cell which consists of one or more cells connected in series.
- A battery is designed based on the application, or amount of potential / current required for a specific use.
- Batteries are broadly classified into two types:
 - Primary battery (or) non-rechargeable battery
 - Secondary battery (or) rechargeable battery.

PRIMARY BATTERY

- They are non-rechargeable.
- They are made of irreversible cells.
- After usage, they are discarded.
- They are not ecofriendly.
- Short lifespan.

e.g. Dry cell

SECONDARY BATTERY

- They are rechargeable.
- They are made of reversible cells.
- They can be reused.
- They are ecofriendly.
- Long lifespan.

Ex: Pb - Acid storage battery

→ Dry cell: [Leclanche cell (or) Zn-C battery].

It consists of

a cylindrical

Zn container.

as anode.

Anode is in contact

and

with $\text{NH}_4\text{Cl} + \text{ZnCl}_2$.

Graphite (or) C-rod acts as cathode. Cathode

is in contact with MnO_2 and C [granules
of C (or) graphite]. Granules of C are added

to MnO_2 to increase the conductivity.

Electrode Reactions includes primary and

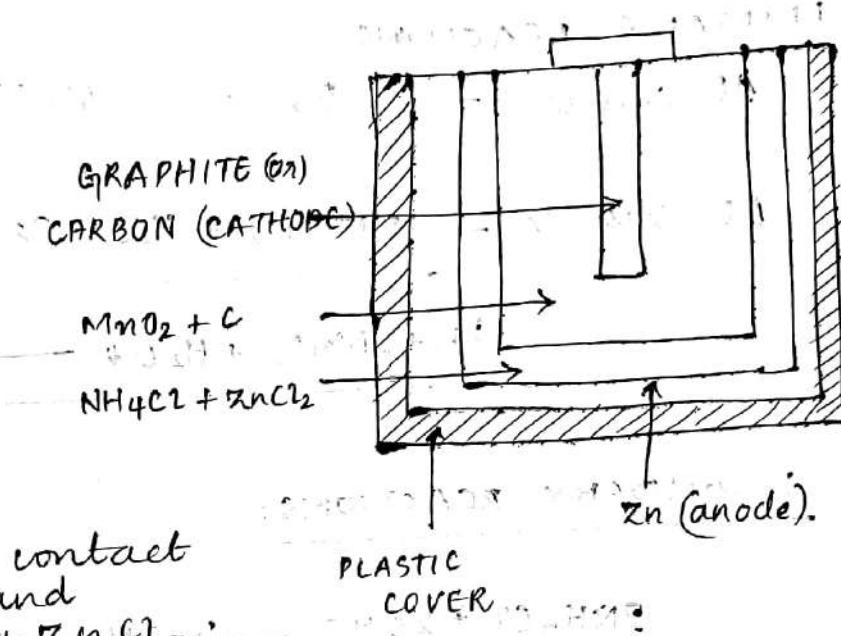
secondary reactions. During primary reaction

Zn ions and hydroxyl ions (OH^-) are formed

During secondary reactions, a Zn complex is

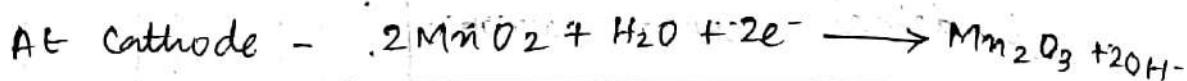
formed. As the final product is a complex,

dry cell works as primary battery.

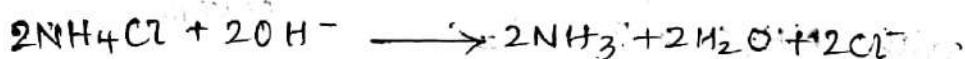


Electrode Reactions:

• PRIMARY REACTIONS:



• SECONDARY REACTIONS:



• EMF (or) potential of the battery is 1.5V.

• Applications:

→ It is used in appliances where small current is required.

→ It is used in toys, watches, radios, transistors, etc.

• Disadvantages:

→ Battery runs down even when it is not in use.

→ It has to be discarded after use.

Li-ION BATTERY:

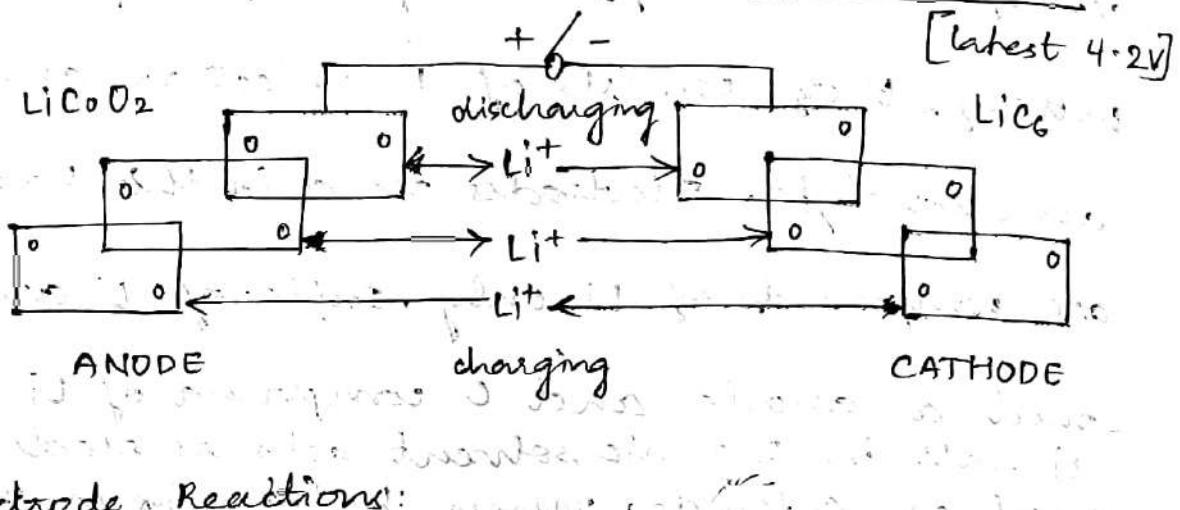
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Li-ion batteries are the most successfully developed secondary battery. Like any other battery, they consists of two electrodes and an electrolyte. Electrodes used in this battery are compounds of Li only. Oxides of Li are used as anode and a compound of Li are Li salt in organic solvent acts as electrolyte. used as cathode. When battery is in working condition, insertion and extraction of Li ions are observed b/w electrodes.

When Li-ion is coming out of any electrode, the process is said to be extraction and the reverse process is insertion. During discharging process, extraction of Li-ion from anode and insertion of Li-ion to the cathode takes place. The reverse process is observed during charging of battery. It is also observed that there will be change in oxidation state of Co used in anode; i.e., Co gets oxidised from Co^{+3} to Co^{+4} .

during discharging and gets reduced from Co^{+4} to Co^{+3} during recharging.

Potential of the battery is 3.6V to 3.7V .



Electrode Reactions:



Disadvantages:

→ Care must be taken to prevent explosion of the battery as it uses a very reactive element i.e., Li.

→ Proper vents must be provided to the battery.

Advantages / Applications:

- i - It is a secondary battery with good shelf life.
- ii - Potential of the battery is high.
- iii - Depending upon requirement, many nich

batteries can be interconnected in series.
iv - It is used in mobile phones, laptops, cars, etc.

→ Lead Acid Storage Battery:

It is a secondary battery

with lead grid filled

with spongy lead as PbO_2

Anode and Pb grid filled

with PbO_2 as cathode. H_2SO_4 is electrolyte.

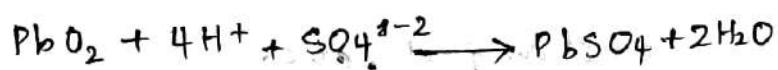
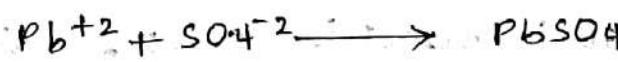
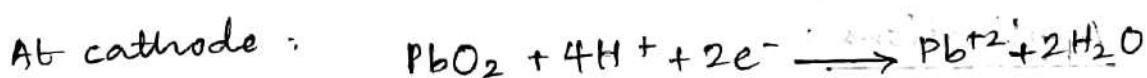
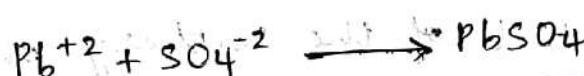
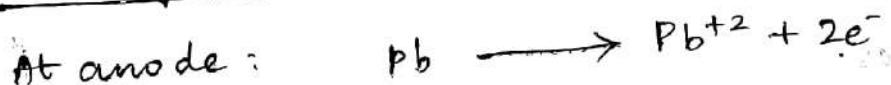
During discharging process, H_2O is formed due

to which viscosity / density of acid decreases

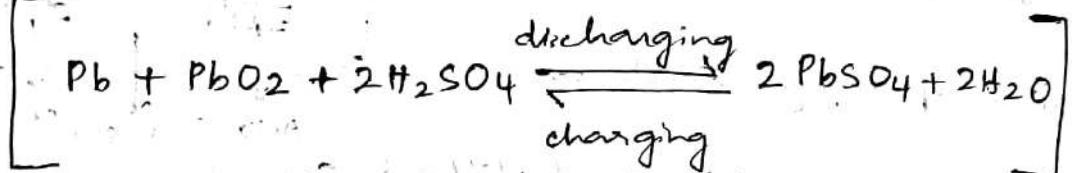
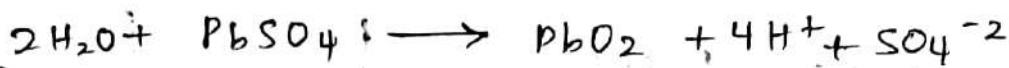
As the products are in cell itself, it can be

recharged and reused.

Discharging reactions:



During Charging :



Potential of the battery depends upon activity.

of concentration of H_2SO_4 used. At 25° , when

7.4% H_2SO_4 is used, potential of the battery
is 1.90V.

Disadvantages:

- i - Frequent recharging decreases the life time of electrodes.
- ii - Potential of the battery may change with change in temperature condition.

Applications:

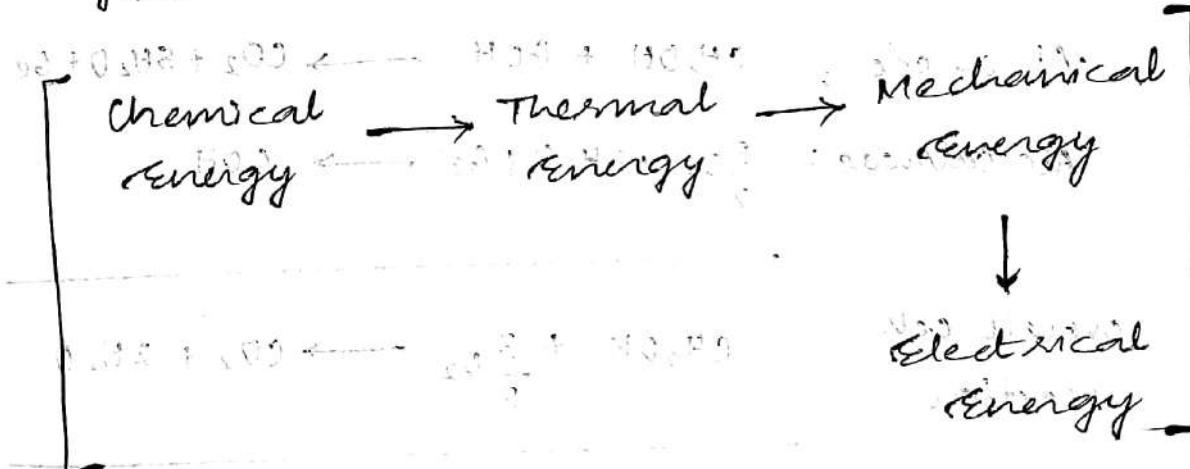
- i - It is used in cars, railway lines, telephone exchanges, etc.

ii. Much maintenance is not required. Occasionally water has to be added since the H_2O product might get evaporated.

* Fuel Cells: A fuel cell works like

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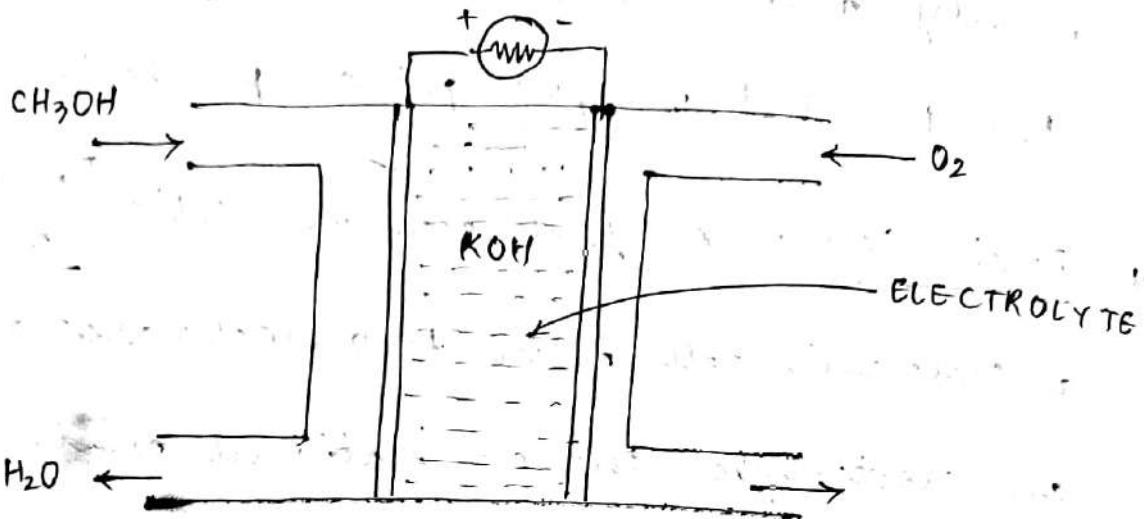
a galvanic cell with two electrodes and an electrolyte. The conventional method of utilizing chemical energy present in a fuel involves following steps:



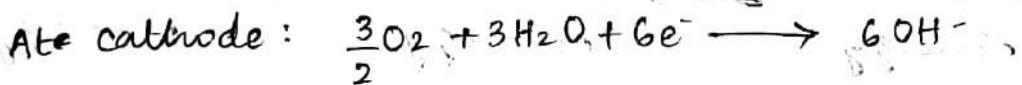
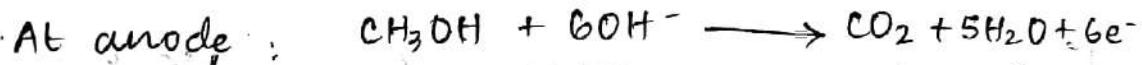
Fuel is continuously supplied to anode, oxidant is supplied to cathode. Therefore, fuel undergoes oxidation reaction and oxidant undergoes reduction reaction.

A fuel cell works continuously as long as fuel and oxidants are supplied.

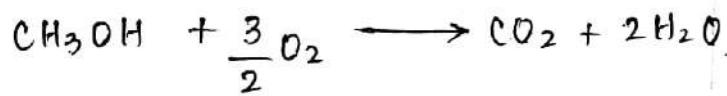
* Methanol - Oxygen Fuel Cell:



Cell Reactions:



Overall cell
reaction:



It consists of two Pt electrodes covered by Ni-Pd catalyst as anode and cathode. CH_3OH (Methanol) is supplied at anode, O_2 is supplied to cathode. Methanol undergoes oxidation reaction, O_2 undergoes reduction reaction. An alkaline electrolyte like KOH is generally (or) commonly used. Potential of the battery is 1.58V.

Advantages

1. The products or emission given out by battery are not harmful or non-toxic.
2. There is no wear and tear in battery. Therefore, maintenance is low.
3. No sound or noise pollution.
4. Reagents used are renewable. ~~renewable~~
~~are ecofriendly~~
5. fuel cells are ecofriendly batteries.
6. Unlike solar cells, they are portable.
7. They can be used continuously as long as fuel and oxidants are supplied.

Disadvantages

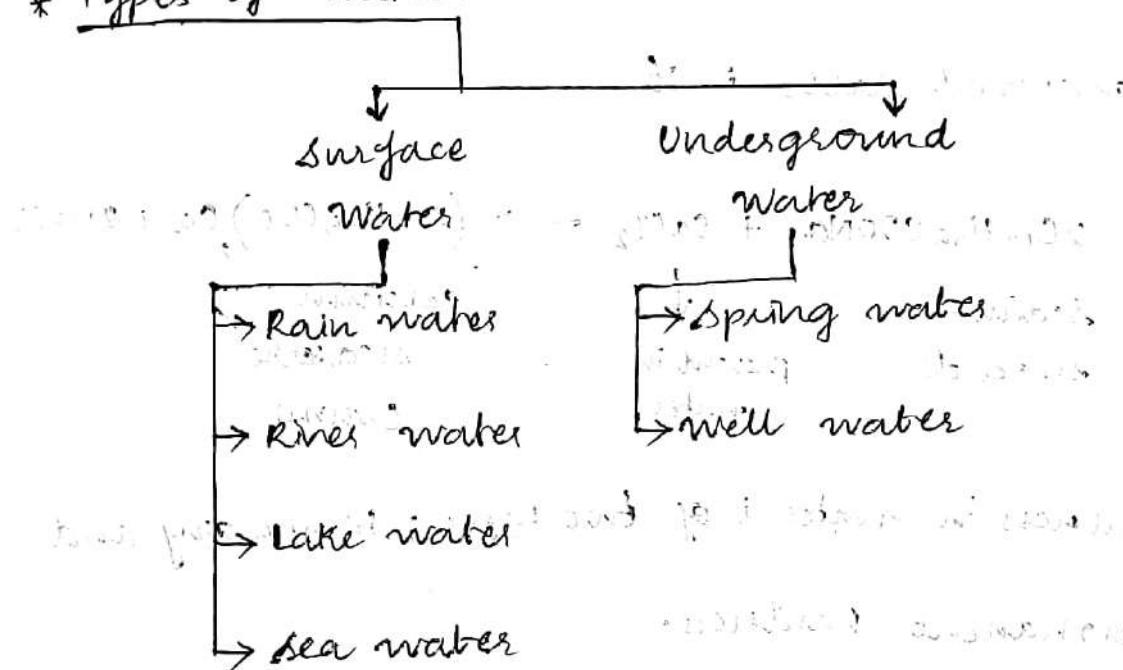
1. Efficiency of the battery decreases when alkaline electrolyte like KOH is used because CO_2 released during reactions reacts with KOH to form potassium carbonate (K_2CO_3). Acid electrolytes are better than alkaline electrolytes.

Applications:

- 1- It is used in generators, spacecrafts, submarines, military vehicles.

Water Chemistry

* Types of Water:



→ Rainwater is considered to be the purest form of water and sea water is the least pure water. sea water has about 3.6% dissolved salts along with organic impurities. $\underline{2.6\%}$ of the salt among 3.6% is $\underline{\text{NaCl}}$. River and lake water will have much of the dissolved mineral salts.

spring and well waters appear to be clear due to filtering action of soil. They have dissolved

organic impurities.

* Hard water: is that water which does not give lather with soap solution. Instead, it gives white precipitate (or) scum due to certain dissolved salts in it.



sodium stearate present in water

calcium

stearate

Ca(OH)₂

→ Hardness in water is of two types; temporary and

permanent hardness.

→ Temporary hardness, (or) carbonate hardness:

Temporary hardness in water is due to dissolved bicarbonates of Ca and, Mg and other heavy metals. It is called so because it can be removed by boiling and filtering.



↓ insoluble and is
filtered

Temporary hardness is removed by adding lime water to water.

Permanent Hardness:

06 Feb
Thurs

It is caused due to dissolved salts of chlorides and sulphates of Ca, Mg and other heavy metal ions in water.

Permanent hardness cannot be removed by boiling.

The methods which are used to remove hardness causing salts present in water are known as softening methods.

Water which is free from hardness causing salts is known as soft water.

Hardness is expressed in terms of equivalents of CaCO_3 .

Hardness can be defined as no. of equivalents of CaCO_3 with which dissolved salts may combine.

$$\text{Equivalents of } \text{CaCO}_3 = \frac{\text{Mass of Hardness causing salts} \times \frac{\text{Mass of } \text{CaCO}_3}{\text{M.W. of Hardness causing substance}}}{}$$

Q) What is hardness due to 60 mg of $MgSO_4$.

Sol)

$$60 \times \frac{10}{120} = 50 \text{ equivalents of } CaCO_3$$

Units of hardness in Water: There are four ways

by which the hardness can be expressed:

1 - ppm (parts per million) - It is parts of $CaCO_3$ equivalents present in 10^6 parts of water.

2 - Milligrams per litre (mg/lit) - It is mg of $CaCO_3$ present in a litre of water.

3 - Degree Clarke ($^{\circ}C_2$) - It is equivalents of $CaCO_3$ present in 70000 parts of water.

4 - Degree French ($^{\circ}F_2$) - It is parts of $CaCO_3$ equivalents present in 10^5 parts of water.

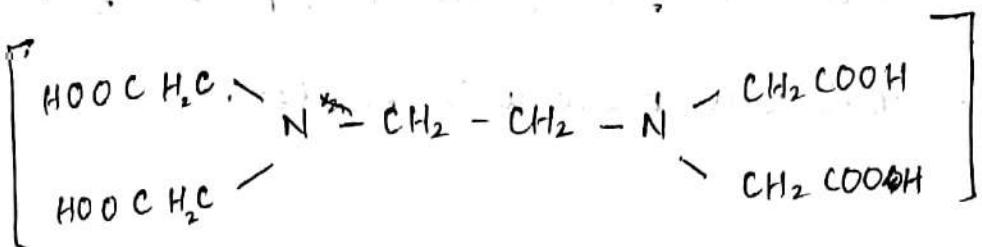
$$1 \text{ ppm} = 1 \text{ mg/lit} = 0.07 \text{ } ^{\circ}C_2 = 0.1 \text{ } ^{\circ}F_2$$

→ Determination of hardness present in water by

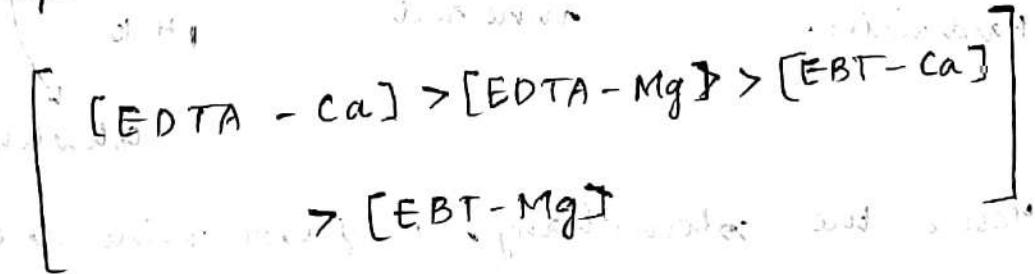
EDTA method:

EDTA is Ethylenediamine tetraacetic acid

EDTA Structure

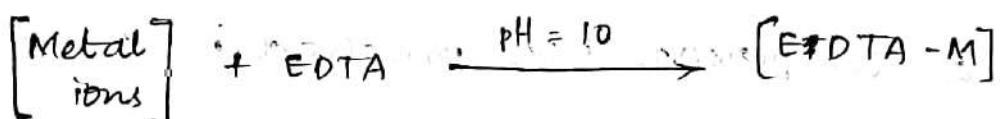


It is a complexometric method, in which EDTA forms quantitatively 1:1 stable complex with metal ions like Ca^{+2} , Mg^{+2} present in water. EBT (Eriochrome Black-T) is used as indicator which is an alcoholic solution of blue dye. To maintain pH = 10, for complex formation, mixture of Ammonium chloride and (NH_3Cl) is used as Buffer solution. EDTA metal ion complexes are colourless and more stable. EBT metal ion complexes are wine-red in colour and less stable. Order of stability of complexes is:



when EDTA is added to hard water with buffer

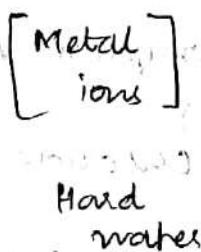
solution and EBT, it forms complexes with free metal ions present in water.



Hard water

colorless

EBT forms complexes with metal ions to give wine-red colour.

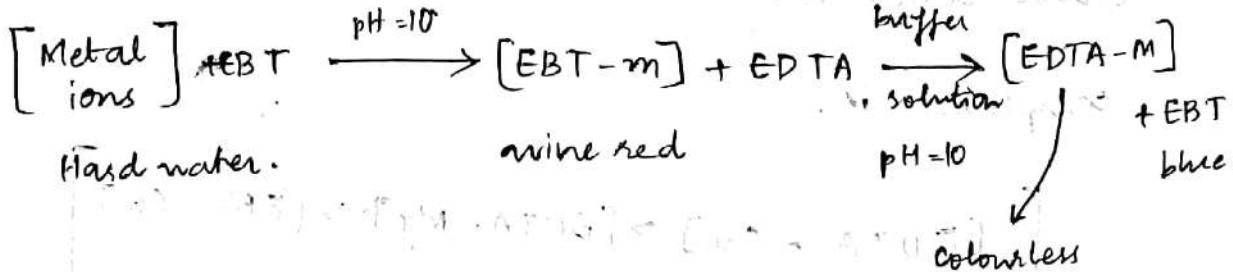


wine-red colour

Hard water

colorless

In the end, EDTA breaks EBT metal ion complex to form complex with the released metal ions leaving EBT free.



Hard water.

wine red

pH=10

blue

colorless

Hence the colour change is from wine-red to blue (blue = end point).

Procedure:

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1. Preparation of standard Hard Water:

1g of CaCO_3 dissolved in 1 litre distilled water.

2. Standardization of EDTA:

3. Determination of Total Hardness present in given Water sample.

4. Determination of Permanent Hardness present in given water sample.

5. Determination of temporary hardness present in given water sample.

Water treatment - Hard water
Temporary Hardness

[Temporary hardness] \rightarrow Ca^{2+} & Mg^{2+}
[Permanent hardness] \rightarrow Al^{3+} & Fe^{2+}

Water treatment - Hard water
Temporary Hardness

Water treatment - Hard water
Temporary Hardness

Calculations:

Step 1 - 1 ml of standard Hard water
 \rightarrow = 1 mg of CaCO_3 .

Step 2 - standardization of EDTA.

20ml of $\xrightarrow{\text{S.H.W}}$ V_1 ml of EDTA
 \downarrow

20mg of
 CaCO_3

$$[1 \text{ ml of EDTA} = \frac{20}{V_1} \text{ mg of } \text{CaCO}_3]$$

Step-3 - determination of total hardness in sample water.

20ml of $\xrightarrow{\text{Sample water}}$ V_2 ml of EDTA

$$[V_1 \text{ ml of EDTA} = \frac{20V_2}{V_{01}} \text{ mg of } \text{CaCO}_3]$$

$$[\text{Total hardness} = \frac{1000V_2}{V_1} \text{ mg/lit (or) ppm}]$$

Step-4 - determination of permanent Hardness in sample water.

20ml of boiled water $\rightarrow V_3$ ml of EDTA

$$\left[\text{Permanent hardness} = \frac{1000 \times V_3}{V_1} \text{ mg/l lit. (or) ppm} \right]$$

Step - 5 - Determination of temporary hardness in sample water

$$\left[\text{Temporary hardness} = \frac{1000 (V_2 - V_3)}{V_1} \text{ mg/l lit. (or) ppm} \right]$$

Problems:

Q) A standard hard water contains 15mg of CaCO_3 per litre. 20ml of this required 25ml of EDTA solution. 100ml of sample water required 18ml of EDTA. The same amount of water sample after boiling required 12ml of EDTA.

Calculate temporary hardness of water.

(a) 1ml hard water \rightarrow 15mg of CaCO_3

20ml of SHW \rightarrow 25ml of EDTA

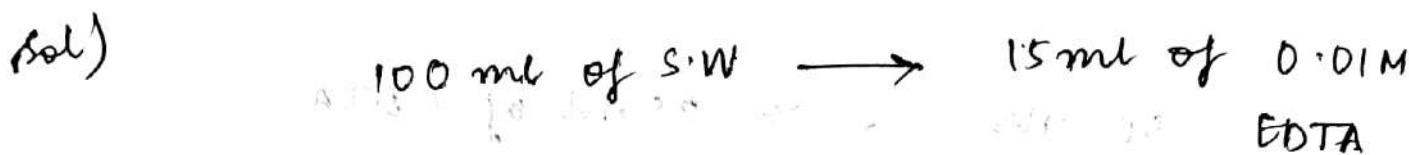
$20 \times 15 \text{ mg of } \text{CaCO}_3 \rightarrow 25 \text{ ml of } \cancel{\text{EDTA}}$

$$\left[1 \text{ ml of EDTA} = \frac{20 \times 15 \text{ mg of } \text{CaCO}_3}{25} \right]$$

∴ 100ml water required $\rightarrow 12$ mg of CaCO_3 .

100ml sample water $\rightarrow 18 \text{ ml of EDTA}$

Q4) 100 ml of sample hard water required 15 ml of 0.01M EDTA. 100 ml of same sample water after boiling consumed 8 ml of 0.01M EDTA. calculate temporary hardness.



$$\text{Total hardness} = M_w \times 100 \times 1000$$

$$V_w = 100 \text{ ml}$$

$$M_1 V_1 = M_2 V_2$$

$$M_w = ?$$

$$V_{EDTA} = 15 \text{ ml}$$

$$M_{EDTA} = 0.01$$

$$\text{Total hardness} = 0.0015 \times 100 \times 1000 = 150 \text{ ppm}$$

$$V_w = 100 \text{ ml}$$

$$M_w = ?$$

$$V_{EDTA} = 8 \text{ ml}$$

$$M_{EDTA} = 0.01$$

$$M_1 V_1 = M_2 V_2$$

$$M_w = \frac{0.01 \times 8}{100} \\ = 0.008$$

$$\text{Permanent hardness} = 0.008 \times 100 \times 1000$$

$$= 800 \text{ ppm}$$

Determination of Alkalinity Present in Water:

12 Feb
Med

Alkaline water will have pH greater than 7.

Alkalinity in water is mainly due to 3 types of ions: OH^- , CO_3^{2-} , HCO_3^- .

Alkalinity is determined by acid base titration

using phenolphthalein and methyl orange

indicators.

Alkalinity in water is usually expressed in ppm

(i) mg/litre

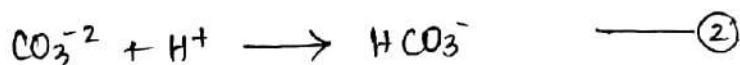
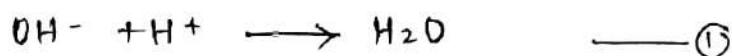
Alkalinity can be due to any of one type of ion mentioned above or due to their combination except the combination of OH^- and

HCO_3^- ions.



* Therefore, alkalinity can never be due to all the 3 ions at a time.

The reactions involved in the titration are:



→ Procedure:

1 - Acid of known strength is taken in burette and known volume of alkaline water with phenolphthalein indicator is taken in conical flask.

2 - Water turns pink in colour. It is titrated against acid ~~makes~~ until it becomes colorless, To the same water sample, methyl orange indicator is added then water turns yellow in colour. When it is titrated, end point is red in colour.

Phenolphthalein end pt. marks the completion of reaction no. ① and $\frac{1}{2}$ of reaction ②. Then,

the acid consumes. After P., endpoint upto M⁺ marks the completion of reaction ③ and another 1/2 of reaction ②.

→ Calculation: Volume of water sample taken
= 100 ml

$$\text{concentration of Acid} = nN$$

$$\text{phenolphthalein end point} = V_1 \text{ ml}$$

$$M \text{ end point} = V_2 \text{ ml}$$

$$P = \left(\frac{V_1 n}{100} \right) 50 \times 1000 \text{ ppm}$$

$$M = \left[\frac{(V_1 + V_2) n}{1000} \right] \times 50 \times 1000 \text{ ppm}$$

by comparing P and M values using the table,
given value type of alkalinity can be determined.

TYPE OF ALKALINITY	OH^-	CO_3^{2-}	HCO_3^-
$P=0$	NIL	NIL	M
$P = 1/2 M$	NIL	$2P$	$M - 2P$
$P > 1/2 M$	$2P - M$	$1/2(M-P)$	NIL
$P = M$	M	NIL	NIL

Q) 100 ml of sample water neutralizes exactly 12 ml of 0.1 N HCl using methyl orange indicator. Determine the type of alkalinity.

Sol) P=0 indicates alkalinity is due to only HCO_3^- ions.

$$[\text{N}_{\text{HCO}_3^-} \times V_{\text{HCO}_3^-} = \text{N}_{\text{HCl}} \times V_{\text{HCl}}]$$

$$\text{N}_{\text{HCl}} = 0.12 \text{ N} \quad \text{N}_{\text{HCO}_3^-} = 0.0144 \text{ N}$$

$$V_{\text{HCl}} = 12 \text{ ml} \times 0.05 \text{ (from above)} = 0.6 \text{ ml}$$

$$V_{\text{HCO}_3^-} = 100 \text{ ml}$$

$$\text{wt. of } \text{HCO}_3^- = \text{Normality of } \text{HCO}_3^- \times \text{eq.wt.}$$

$$\text{wt. of } \text{HCO}_3^- = 0.0144 \times 61$$

$$\text{wt. of } \text{HCO}_3^- = 0.8784 \text{ g}$$

$$\text{eq.wt. of } \text{CaCO}_3 = 0.8784 \times \frac{50}{60}$$

$$= 720 \text{ mg}$$

eq.wt of CaCO_3

Q) 100 ml of sample required 4 ml of N/50 H_2SO_4

for neutralization - repro P and pt. another

16 ml of same acid was needed for titration

upto M and pt. Determine the type of alkalinity

$$\text{sol) } P = 4 \text{ ml}$$

$$M = 16 + 4 = 20 \text{ ml}$$

by comparing, $P < \frac{1}{2} M$

\therefore Alkalinity is due to CO_3^{2-} and HCO_3^-

Carbonate alkalinity:

$$N_{\text{H}_2\text{SO}_4} \times V_{\text{H}_2\text{SO}_4}$$

$$0.02 \times 2 \times 4 = 2P$$

$$V_{\text{CO}_3^{2-}} = 100 \text{ ml}$$

$$\text{wt}_{\text{CO}_3^{2-}} = 0.048 = 0.0016 N \times 30$$

$$\text{eq. wt of CaCO}_3 = 0.08 \text{ g}$$

$$\text{eq. wt of HCO}_3^- = 0.072 \text{ g.}$$

* softening of water by ion - exchange

[13 Feb
Thurs]

process: (Deionisation method)

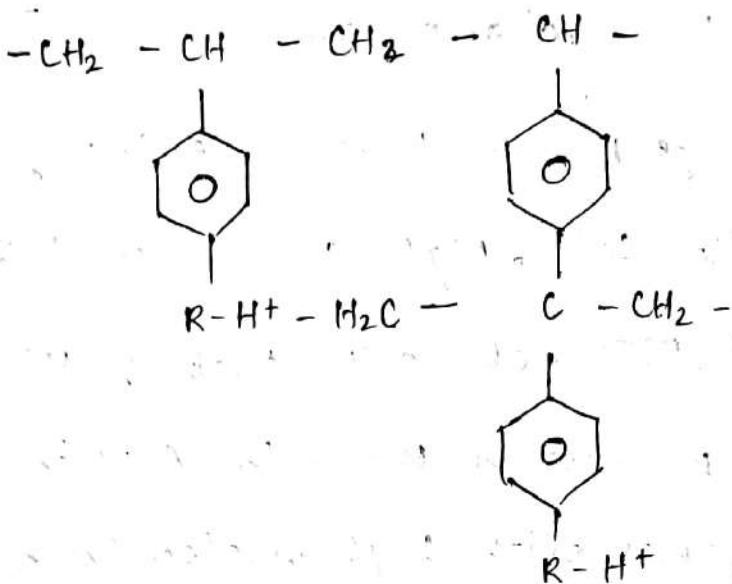
ion - exchange process involves exchange of cations like Ca^{+2} , Mg^{+2} and anions like Cl^{-} , SO_4^{-2} , HCO_3^- , etc with that of H^+ and OH^- ions present in the resin. A resin is an organic polymer with high molecular weight, insoluble, highly cross-linked, porous structure. Ion - exchange process consists of cation exchanger and anion exchanger.

→ cation exchanger: it is filled with cation ex-

change resin which is

- Organic polymer
- High molecular weight
- Insoluble
- Highly cross-linked
- Porous structure

acidic functional group is usually used.
Styrene - divinyl benzene co polymer with



Ex: commercial cation exchangers

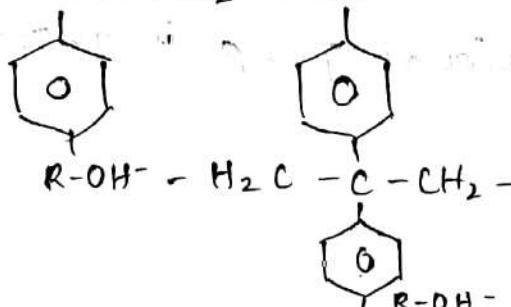
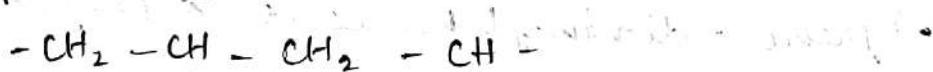
Amberlite IR 120

Dowex 50

→ Anion Exchanger: is it is filled with anion E.R.

- Organic polymer
- High molecular weight
- Insoluble
- Highly cross-linked
- Porous structure

Styrene divinyl Benzene with basic functional groups is usually used

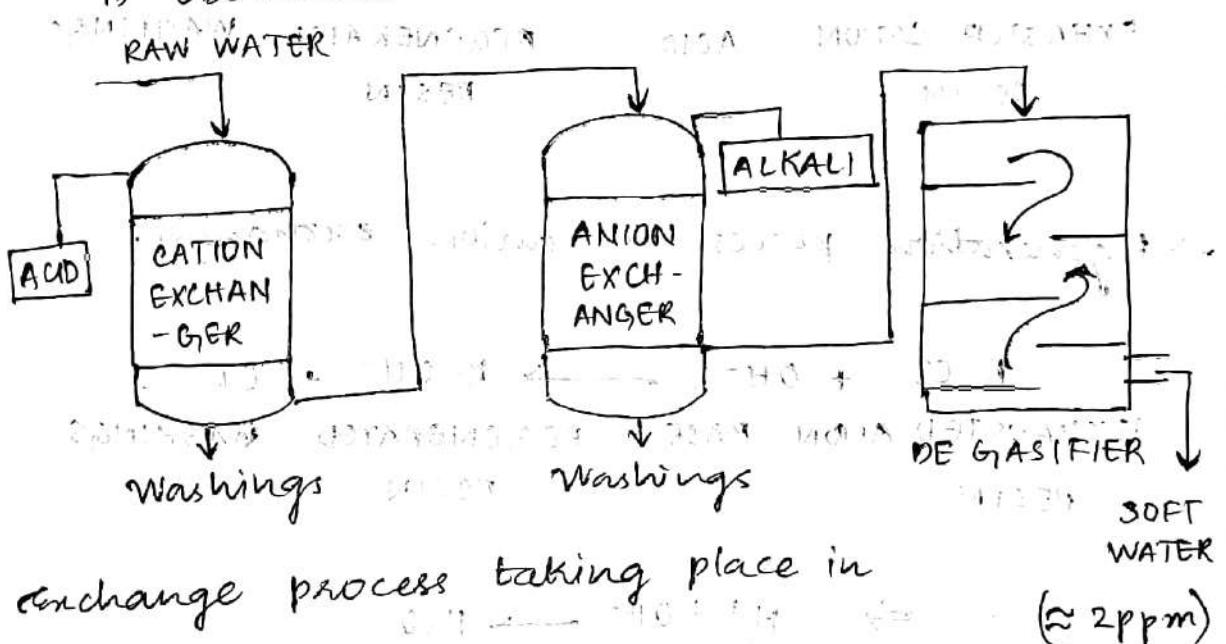


Ex: Commercial Anion exchangers

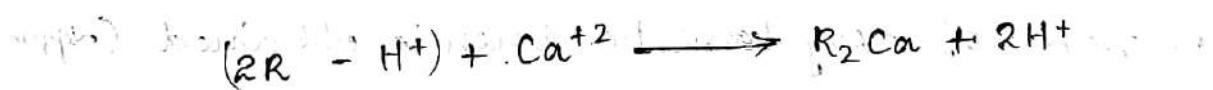
Amberlite IR 200

Dowex - 3

→ Procedure / Process: Raw water is first passed into cation exchanger then into anion exchanger and finally into big degasifier. Water of very low hardness of approximately 2 ppm is obtained.

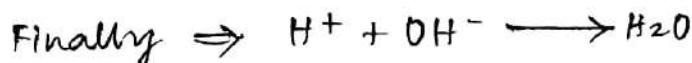


exchange process taking place in
anion exchanger:



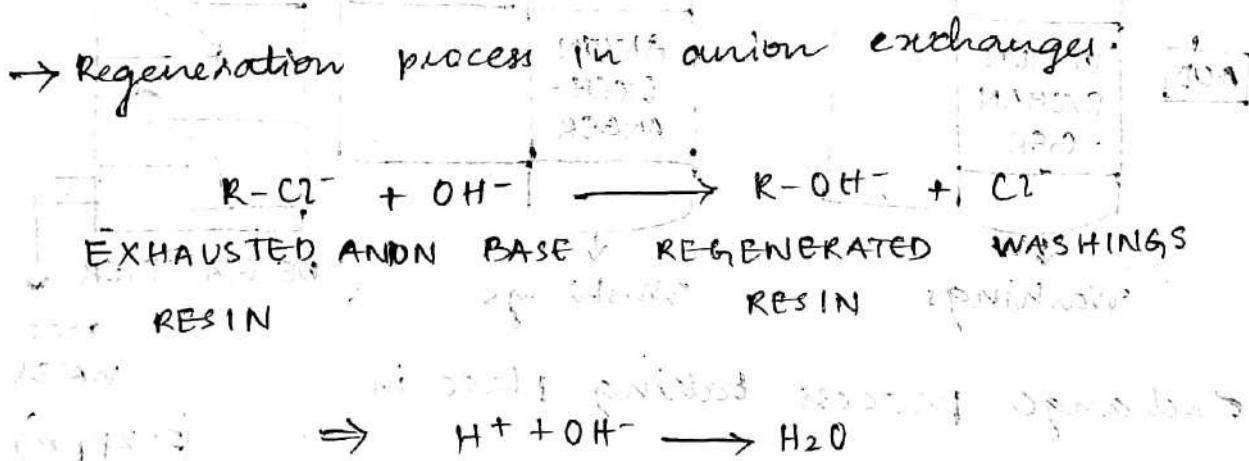
Cation Hard Resin Resin In water water

Exchange process taking place in anion exchanger:



After a period of time, the resins will get exhausted. Exhausted resins are regenerated by regeneration process in which cation exchange resin is treated with acid and anion exchange resin is treated with base/alkali.

→ Regeneration process in cation exchanger:



→ Advantages:

- 1 - water of very low hardness is obtained (0 ppm).
- 2 - Highly acidic or highly alkaline water can be softened by this process.
- 3 - Dissolved gases can be removed easily.

→ Disadvantages:

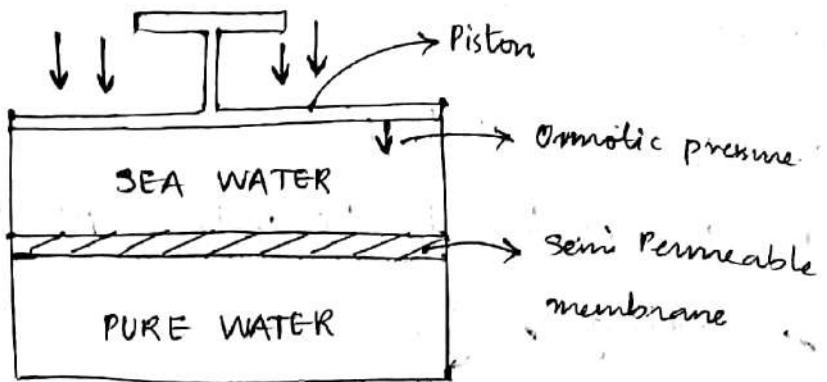
- 1- cost of resin is high;
- 2- the process has to be interrupted for regenerating resins.

* Desalination Process: The process by which dissolved salts are removed is known as desalination process. Most commonly used methods are:

- 1- Multi Stage Flash Distillation Method.
- 2- Reverse Osmosis.
- 3- Electrodialysis.

* Reverse Osmosis Process: Osmosis is a natural process which takes place where two solutions of different concentrations are separated by semipermeable membrane. Due to osmotic pressure, solution of low concentration will move into the high concentration side.

In reverse osmosis process, pressure greater than osmotic pressure is applied on high concentration side / sea water side so that water moves from high concentration to low concentration side.



Cellulose acetate (or) a polymer known as poly methyl methacrylate (PMMA) is used as semi-permeable membrane which can be replaced every two years.

Advantages:

- 1 - Maintenance is low.
- 2 - The process removes silica, sand particles, colloidal particles along with dissolved salts.

Disadvantages:

- 1 - Cost of semi-permeable membrane is high.
- 2 - It removes all the minerals which might be advantageous.

Corrosion

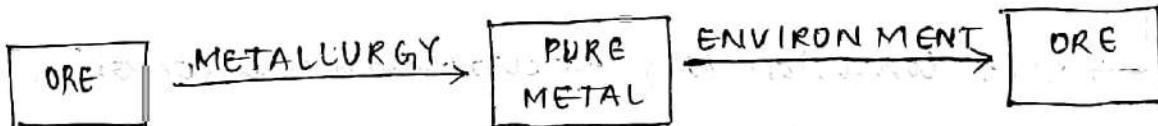
17 Feb

Mon

Destruction or decaying of a metal due to chemical reaction.

(or) electrochemical attack in environment to form ore is known as corrosion.

- Metal in its natural form exists as ore.
- Ore is the combined state of a metal. Ore possesses less energy hence it is thermodynamically stable form.



ORE	METALLURGY	PURE METAL	ENVIRONMENT	ORE
less energy		High Energy		Combined state of metal
thermodynamically less stable		thermodynamically less stable		
More stable				

When metal undergoes corrosion, it loses its important properties like conductivity, malleability, ductility, tensile strength, etc. Therefore one tries to stop corrosion in metals.

CORROSION:

→ Dry corrosion (or) Direct chemical corrosion

1 - Oxidation

2 - corrosion due to
other gases

a) Stable corrosion

b) Unstable corrosion

c) Porous corrosion

d) Volatile corrosion

3 - Liquid Metal corrosion

→ Wet corrosion (or) Electrochemical corrosion

1 - Galvanic corrosion

2 - Pitting corrosion

3 - Water line corrosion

4 - Differential aeration

→ Dry corrosion - is observed when metal reacts directly with gases to form a corrosive product in dry condition. A direct chemical product is formed.

1- Oxidation corrosion - when metal reacts with oxygen to form metal oxide, the oxidation corrosion occurs. The metal oxide layer formed maybe stable, unstable porous or volatile. Extent of corrosion depends upon nature of metal oxide layer formed.

a) Stable Oxidation corrosion

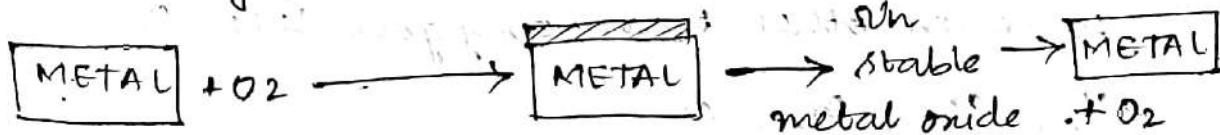
Ex: Pb, Sn, Al, Cu, etc.

Stable metal oxide layer acts as a protective coating.

b) Unstable Oxidation corrosion:

It involves formation of unstable metal oxide layer. Metal oxide, which is a corrosive product is unstable, so corrosion is not observed in metals.

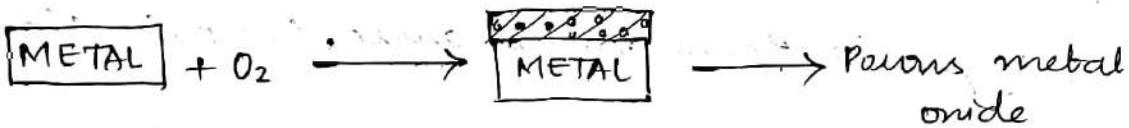
Ex: Au, Ag, Pt, etc.



c) Pores Oxidation Corrosion:

Metal Oxide layer formed will have pores which allows oxygen to enter into the next layer of metal. Rate of corrosion is high.

Ex: Reaction of copper with air

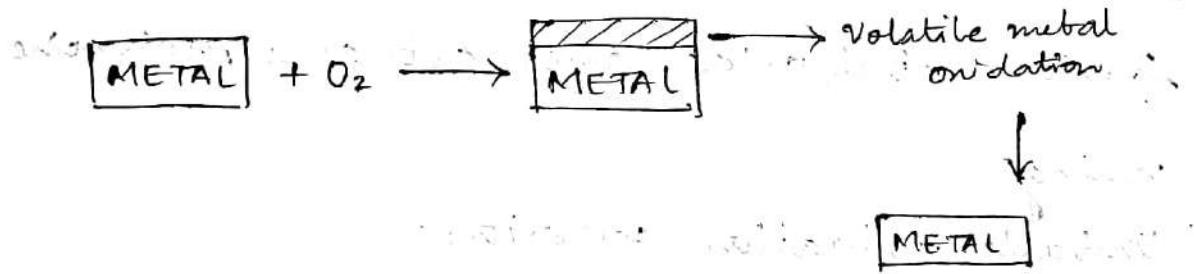


d) Volatile Oxidation corrosion:

Metal oxide layer formed is volatile in nature. Therefore, always fresh surface of metal will be ready to undergo corrosion.

- Rate of corrosion is very high.

Ex: Molybdenum (Mo)



Rate of corrosion is very high

e- corrosion due to other gases:

Under dry conditions, if metal undergoes corrosion other than oxygen like Cl_2 , H_2 , SO_2 , Br_2 , etc.

Extent of corrosion depends upon the nature of corrosive product formed. It could be a protective layer, or non-protective layer.

(Ex: SnCl_4 on Sn is a non-protective layer.)

AgCl on Ag is a protective layer.

3- Liquid metal corrosion:

When a hot liquid metal flows on solid metal surface, this type of corrosion is observed.

(Ex: It is seen in nuclear reactors.)

→ wet corrosion (or) electrochemical

corrosion:

When metal comes in contact with liquid (or) conducting medium. This type of corrosion is observed (or) when 2 dissimilar metals are completely or partially immersed in a solution, electrochemical corrosion takes place.

It involves formation of anodic and cathodic areas. At anode, Oxidation reaction takes place where metal gets oxidised. Therefore anodic

19 Feb
Wed

part of the metal is said to be undergoing corrosion.

At cathode, reduction reaction takes place.

A metal cannot be reduced further therefore ions present in the solution gets reduced to form OH^- ions, (O_2) O_2^- ions.

Ions from anode and cathode diffused towards each other to form a corrosive product near a ~~at~~ cathode. Therefore cathodic part is unaffected part.

Electrolytic Corrosion

Involves the action of an external DC source.

An external DC source is connected between anode and cathode which starts an oxidation reaction at anode and reduction reaction at cathode.

The oxidation reaction at anode is:

$$\text{M} \rightarrow \text{M}^{+} + \text{e}^{-}$$

The reduction reaction at cathode is:

$$2\text{H}_2\text{O} + 2\text{e}^{-} \rightarrow 2\text{OH}^{-}$$

Thus, the overall reaction is:

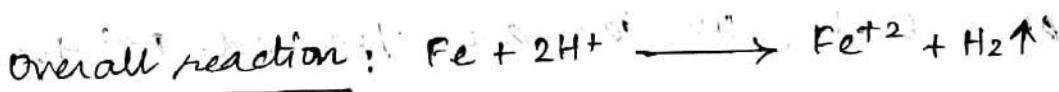
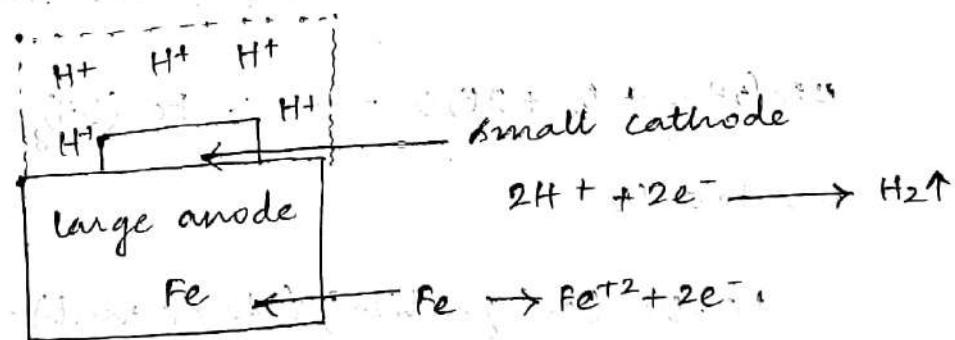
$$\text{M} + 2\text{H}_2\text{O} \rightarrow \text{M}^{+} + 2\text{OH}^{-}$$

* Mechanism of electrochemical corrosion:
 Consider a metal Fe undergoing electrochemical corrosion. It forms anodic and cathodic areas. At anode, oxidation reactions take place. Type of reduction reactions taking place at cathode depends upon nature of solution with which metal is in contact. Therefore, reduction reactions at cathode will be:

- evolution of H type
 (OR)
- Absorption of O₂ type.

→ Evolution of H type:

This type of cathodic reactions are observed when metal is in contact with acid.



Anodic area is large and forms Fe⁺² ions.

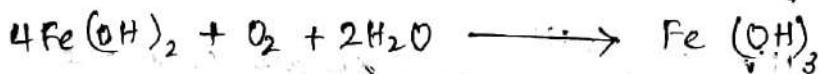
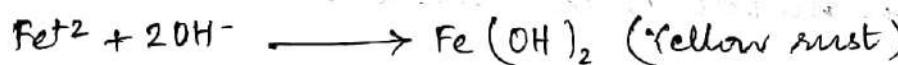
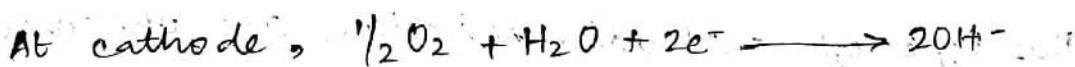
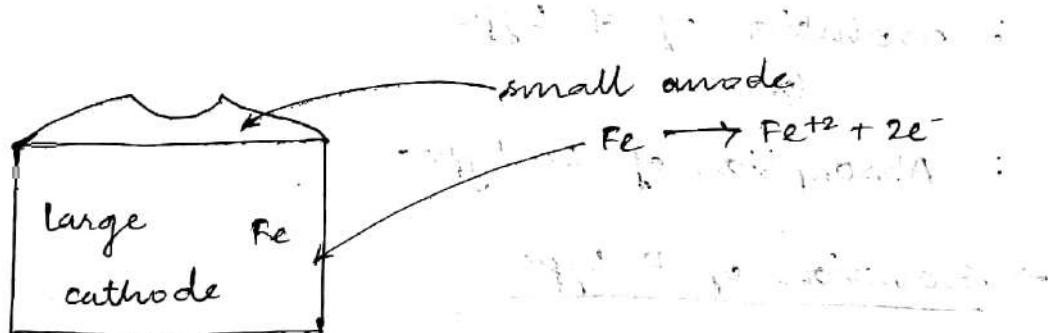
Therefore anode undergoes corrosion.

Metals placed above electrochemical H in elektrochemical series can displace H₂ gas from acid.

→ Absorption of O₂ type:

This type of cathodic reactions are observed when metal is in contact with neutral or alkaline medium in presence of O₂.

Anodic area is small.



limited O₂



At cathode, OH⁻ ions are formed - Fe⁺² from anode, OH⁻ from cathode diffuse towards each other to form Fe(OH)₂ (Yellow rust) at cathode.

When enough O_2 is supplied, $Fe(OH)_2$ gets converted to $Fe(OH)_3$ (Ferric Hydroxide). At limited O_2 medium, an ore of Fe magnetite i.e., black rust is formed.

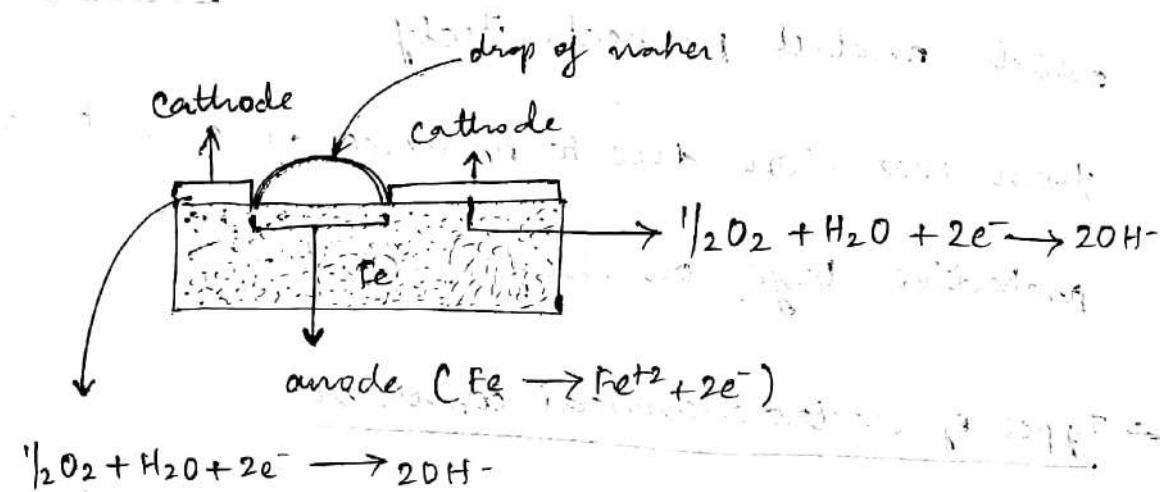
- * passivity is the phenomenon by which metal protects itself from corrosion due to presence of a natural protective layer on surface of it.

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Thurs

→ Types of electrochemical corrosion:
1- pitting corrosion - consider a drop of water on surface of metal. The portion of the metal which is covered by water will have less O_2 supply and the remaining portion will get enough O_2 supply. This sets up O_2 concentration cell due to which small anodic areas are formed and large cathodic areas are formed.

This difference results in formation of pits (or) pinholes (or) cavities in a metal. Therefore

it is called pitting corrosion. It is a non-uniform corrosion resulting in localised accelerated attack. Pitting corrosion is usually observed when there is a crack / break in protective film of a metal.



→ Waterline corrosion. - (Formation of concentration cell).

Consider a steel tank filled with water. The

portion of the tank which is covered by water

will get less O₂ supply and the remaining

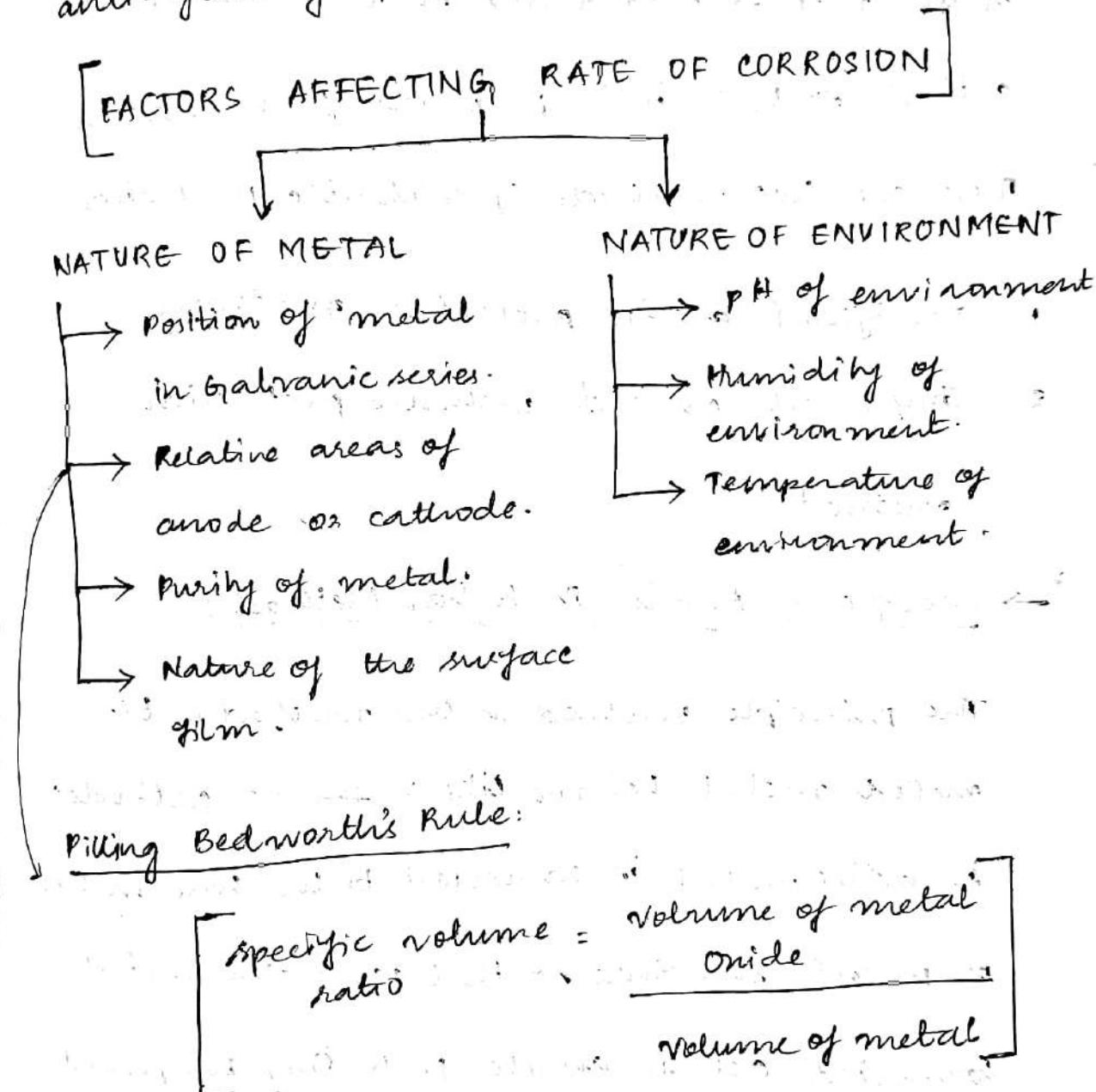
portion will get enough O₂ supply. This results

in formation of O₂ concentration cell. The

portion which is covered by water, acts as

anode and undergoes corrosion.

Ex: Water stored in steel tanks.
Marine plants grown on ocean going ships.
Waterline corrosion can be prevented by using
anti-fouling paints.



Pilling Bedworth's Rule:

$$\text{Specific volume ratio} = \frac{\text{volume of metal}}{\text{oxide volume}}$$

Smaller the specific volume ratio, greater is the rate of oxidation corrosion.

* Corrosion control:

24 Feb
Mon

Cathodic protection method: The principle involved in this method is to make metal behave like cathode so that it is protected from corrosion.

There are two methods of cathodic protection.

- 1 - Sacrificial Anodic protection method,
- 2 - Impressed current cathodic protection method.

* → Sacrificial Anodic Protection Method:

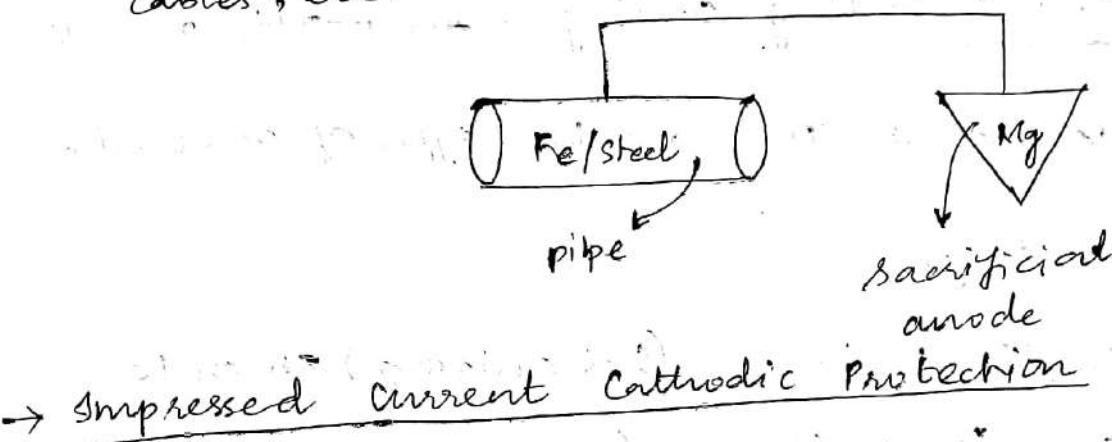
The principle involved in this method is to make metal behave like a ~~cathode~~ anode.

An active metal is connected to the base metal or parent structure so that the active metal connected acts as anode protecting the parent structure. As the active metal is sacrificing itself to protect the parent structure, the metal employed is known as sacrificial anode.

Sacrificial anode has to be replaced

over time to continue the protection of parent structure. More active metals are selected from the electrochemical series.

E.g. For protecting underground pipelines, cables, etc.



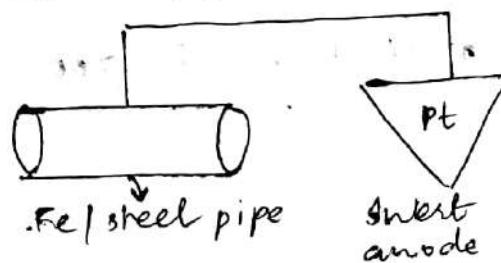
Impressed Current Cathodic Protection

Method:

The principle involved in this method is to make metal behave like a cathode. An impressed current or known amount of current is passed into the parent structure to nullify the corrosion current produced. Direct current is passed into metal with the help of inert anode.

E.g. For protecting underground pipelines, cables,

open water tanks,
cooler tanks, etc.



→ Surface coatings or protective coatings :

A surface coating given on a surface of a metal acts as a barrier between metal and its surroundings.

⇒ Metallic Coating: Coating is ~~metallistic~~ metallic in nature. There are two types of metallic coatings:

- 1 - Anodic coatings. (Galvanising) Zn on Fe.
- 2 - Cathodic coatings. (Tinning)

Tinned articles ~~undergoes~~ are preferred over Galvanised articles for storing food.

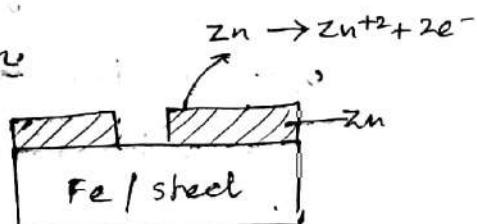
Anodic coatings:

coating metal is anodic in nature.

e.g.: Galvanising.

Galvanising - The process in which Zn is coated on Fe or steel. If pores or

If pores or cracks appear, Zn or coating metal undergoes corrosion.



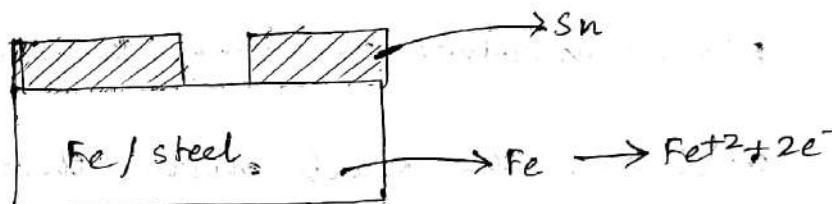
cathodic coatings:

coating metal is cathodic in nature.

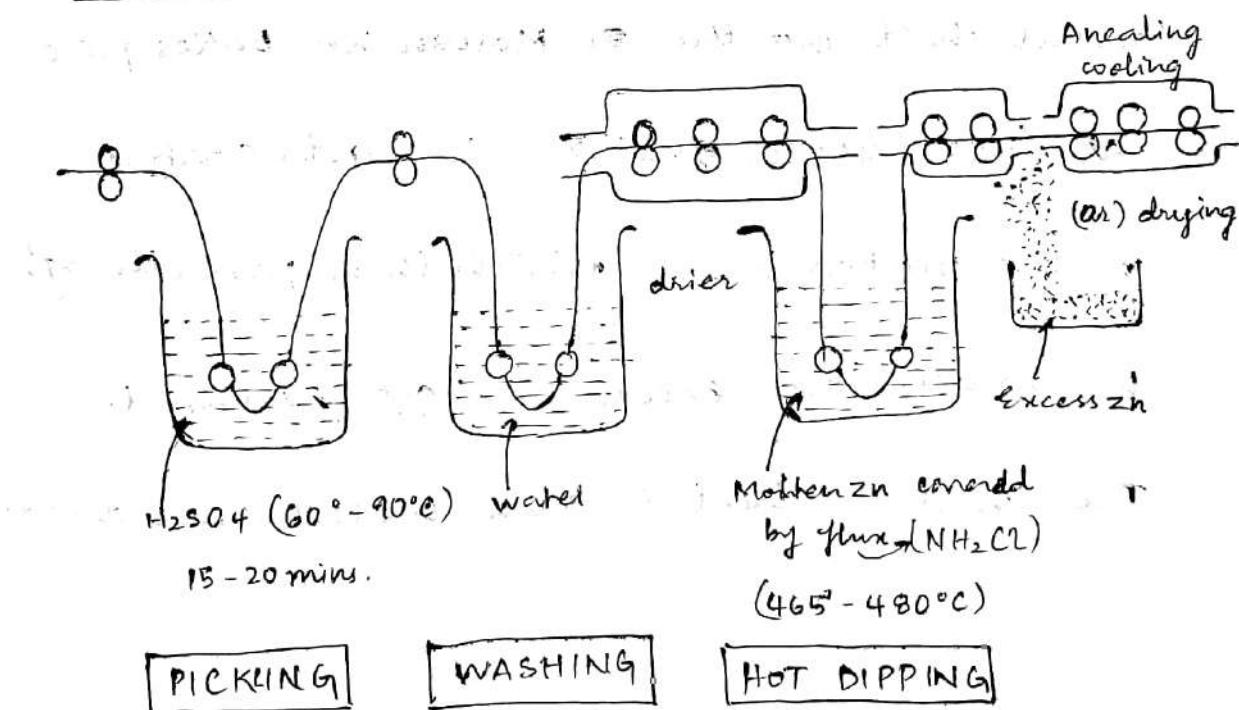
e.g. Tinning

Tinning - The process in which Sn is coated on Fe / steel.

If pores or cracks appears, parent structure undergoes corrosion.



→ Galvanizing By Hot Dipping Method:



Galvanizing using hot dipping metal involves metal the steel sheet which might contain impurities and other matter. Pickling process includes

a container in which concentrated H_2SO_4 is used to clean the metal sheet.

Concentrated H_2SO_4 at $60^\circ - 90^\circ C$ and is p-dipped for 15-20 mins. The metal sheet has to be washed so that the strong acid H_2SO_4 is washed out of the sheet, metal sheet and prevent H_2SO_4 to cause corrosion. The washing process involves washing the sheet with water and then the sheet moves through the rollers for drying process. Next, the hot dipping of

metal sheet into the molten Zn takes place

at $(465^\circ - 480^\circ C)$ and the Zn gets coated

on the metal sheet which then passes through the rollers and excess Zn gets removed.

The metal sheet is then cooled and dried.

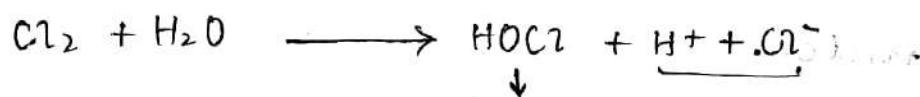
* Disinfection or sterilization of water:

15 Feb
Sat

The following are most commonly used methods:

- 1 - By boiling.
- 2 - By adding bleaching powder (CaOCl_2).
- 3 - By adding chlorine.
- 4 - By adding chloramines.
- 5 - By Ozone treatment.

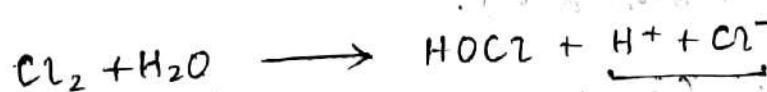
⇒ Bleaching powder (CaOCl_2)



Hypochlorous Acid

⇒ Disinfection by chlorination:

When Cl_2 is added to water, it forms two species



1 - Un-ionised Hypochlorous acid

2 - Ionised Hydrochloric acid at pH: 6.5-8.5

It is unionised HOCl which is responsible for killing all disease causing micro-organisms present in water.

Chlorine is a powerful disinfectant at pH 6.5 - 8.5. Beyond pH 8.5, HOCl gets ionised to H^+ and OCl^- . OCl^- is a weak bactericide.

→ Advantages of chlorination method:

- 1 - chlorine is easily available disinfectant in the form of liquid as well as gas.
- 2 - It takes less time for disinfecting action.
- 3 - It does not introduce any impurities to water.
- 4 - It removes colour, bad taste and odour.
- 5 - It prevents further growth of micro-organisms.

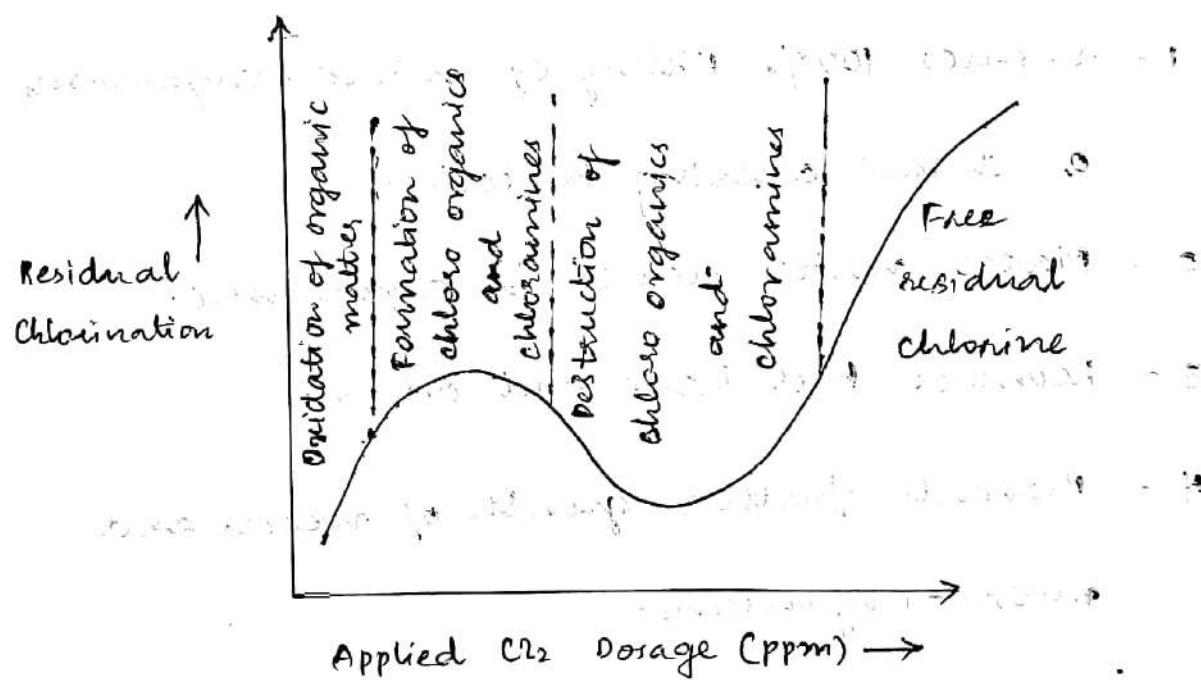
→ Factors affecting disinfecting action of Cl_2 :

- 1 - pH (6.5 - 8.5).
- 2 - Time (more is required).
- 3 - Temperature (more is required).

→ DIS advantages:

- 1 - Care must be taken in storing Cl_2 if it is in the form of a gas.
- 2 - Excess Cl_2 in water causes skin problems, throat irritation, gastrointestinal diseases, etc.

** → Breakpoint Chlorination:



Breakpoint chlorination involves addition of sufficient amount of Cl_2 to water until free residual Cl_2 starts appearing.

Breakpoint chlorination involves:

- 1 - Oxidation of organic matter.

2 - Formation of chloro organics and chloramines.

3 - Destruction of chloro organics and chloramines.

4 - Free residual chlorine starts appearing.

Breakpoint chlorination is defined as the dip

(or) break (or) the point from which free residual chlorine starts appearing.

→ Advantages:

1 - Ensures 100% killing of micro-organisms.

or disease causing bacteria.

2 - Makes water clearer in appearance.

3 - Removes bad taste and odour.

4 - Prevents further growth of weeds and micro-organisms.

SPECIFICATION OF PORTABLE (OR) DRINKING WATER
 (NISO (or) BIS 2012)

Sr. No.	CHARACTERISTIC	ACCEPTABLE LIMIT	PERMISSIBLE LIMIT	UNDESIRABLE EFFECT
1	pH	6.5 - 8.5	No relaxation	Throat, respiratory tract and digestive disorders.
2	Turbidity (ntu)	1	5	Bad taste and odour.
3	Total dissolved salts (TDS) mg/lit	500	2000	Gastrointestinal irritation.
4	Fluorides (mg/lit)	1	1.5	Fluorosis.
5	Free Residual chlorine (mg/lit)	0.2	1	Bad taste and odour.
6	Total alkalinity (mg/lit)	200	600	Unpleasant taste and gastrointestinal tract infection.
7	Total Hardness (mg/lit)	200	600	Unpleasant taste and gastrointestinal tract infection.

24 April
Fri

Polymers

- Polymers can be defined as the large molecules (macro molecules) formed by the linkage of small molecules called monomers.
- Homopolymers are polymers made up of one type of monomer.
Ex: Polyethylene.
- Co-polymer are polymers formed by the reaction between different monomers.
Ex: $\text{BuN}_2\text{-S}$, Thiol, etc.
- Degree of polymerisation - No. of monomer units present in a polymer.
- Functionality is the number of bonding sites in a polymer.
Ex: Ethylene can form two bonds so it is bifunctional.
- Monomers are small functional molecules which combine with each other to form polymer molecules.

→ Types of Polymerisation:

Ex: Polyethene, PVC

Ex: Bakelite

ADDITION POLYMERISATION

1- The mechanism of the reaction involves addition.

2- It is a chain reaction.

3- Monomers with double bonds undergo this type of polymerisation.

4- No neutral molecule is eliminated in the process.

5- The reaction takes place almost at once.

6- At any given time during the reaction, there can be monomer and/or polymers.

7- Thermoplastics are formed.

8- Also known as chain growth polymerisation.

9- Yield of product isn't affected by duration.

CONDENSATION POLYMERISATION

The mechanism of the reaction involves condensation.

It proceeds step wise.

Monomers with other functional groups (CNH_2 , COOH and COCl) undergo this.

In every step there will be elimination of neutral molecules (H_2O or HCl).

Rate of reaction is slow.

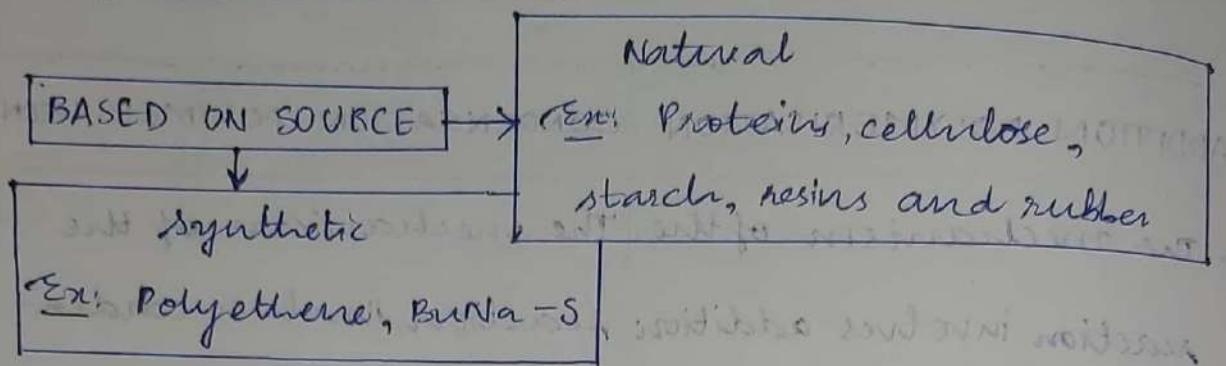
At any instant of time, there will be monomer and intermediates.

Thermosetting plastics are formed.

Also known as step growth polymerisation.

long reaction time yields more products.

→ Classification of Polymers:



BASED ON BACKBONE OF POLYMER CHAIN

Organic polymers

Inorganic Polymers

BASED ON MOLECULAR FORCES

Elastomers

Fibers

Plastics

BASED ON COMPOSITION OF POLYMERS

Homo polymers

Copolymers

BASED ON MODE OF POLYMERISATION

Addition polymers

Condensation polymers

PLASTICS

Thermoplastics

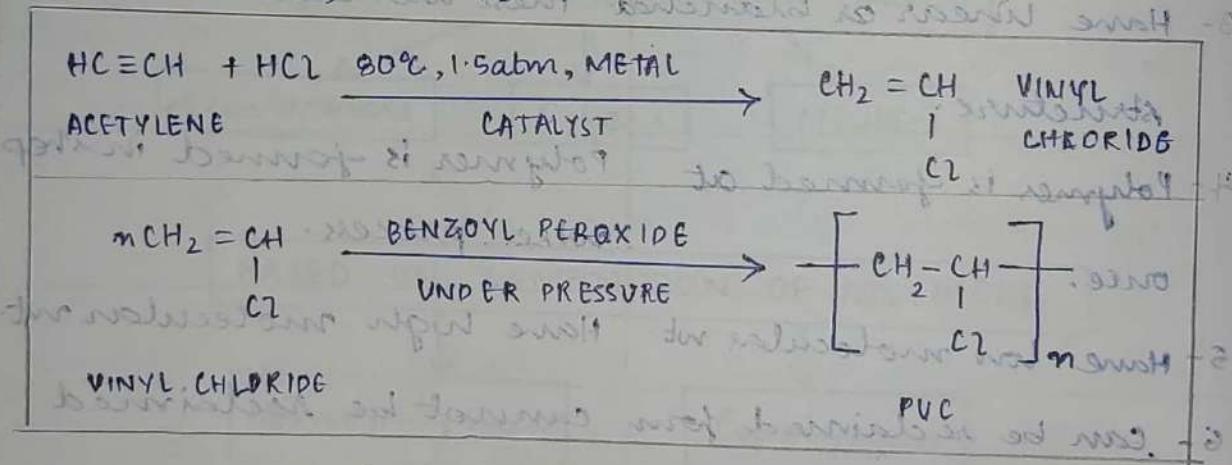
Thermo setting plastics

→ Plastics:

THERMO PLASTICS	THERMOSETTING PLASTICS
1- These polymers soften on heating and harden on cooling any number of times.	These polymers cannot be remoulded into desired shape by heating followed by cooling. Once plastic is set, the shape cannot be changed.
2- Formed by additional polymerisation.	Formed by condensation polymerisation.
3- Have linear or branched structure.	These are cross-linked.
4- Polymer is formed at once.	Polymer is formed in step wise process.
5- Have low molecular wt.	Have high molecular wt.
6- Can be reclaimed from waste.	cannot be reclaimed from waste.
7- Soluble in organic solvents.	Insoluble in almost all solvents.
8- Soft, weak and less brittle.	Hard, strong and more brittle.
9- Ex: PE, PVC, Teflon.	Ex: Bakelite, Vica Formaldehyde resins.

→ Poly Vinyl chloride (PVC): PLASTICS

- 1 - The monomer required for the preparation of PVC is vinyl chloride, which can be prepared by the reaction between acetylene and HCl at 80°C under 1.5 atm pressure using metal catalyst.
- 2 - Obtained vinyl chloride is mixed with water to form an emulsion. The emulsion of vinyl chloride in presence of trace amount of benzoyl peroxide on auto claving under pressure converts to PVC.



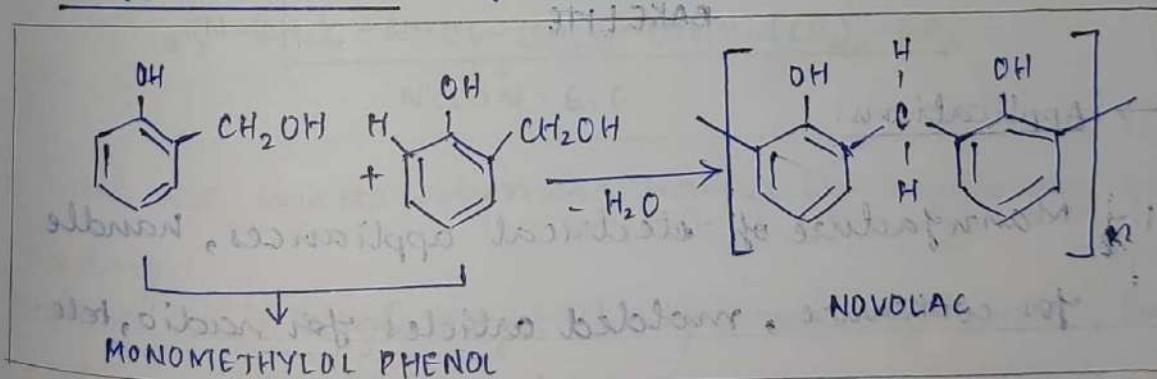
- The polymer is hard and has high softening pt. (148°C).
- It is colourless, odourless and non-flammable.
- Resistant to weather, oil and other chemicals.
- Applications:

- 1 - It can be used in the construction of buildings due to high weather resistance.
- 2 - It is useful in preparing the bottles to pack food substances, water, cosmetics, etc.

Bakelite:

1. It is a polymer formed by the condensation reaction between phenol and formaldehyde.
2. The first step in preparation of Bakelite involves the reaction b/w phenol and formaldehyde to give methylol derivatives of phenol. These can be mono or di or trimethylol phenol. The product formation depends on the ratio of formaldehyde to phenol. The process is called methylolation.

3. In the next step, in presence of acid catalyst, if the molar ratio of phenol to formaldehyde is more than one, then a linear polymer called novolac resin is formed.

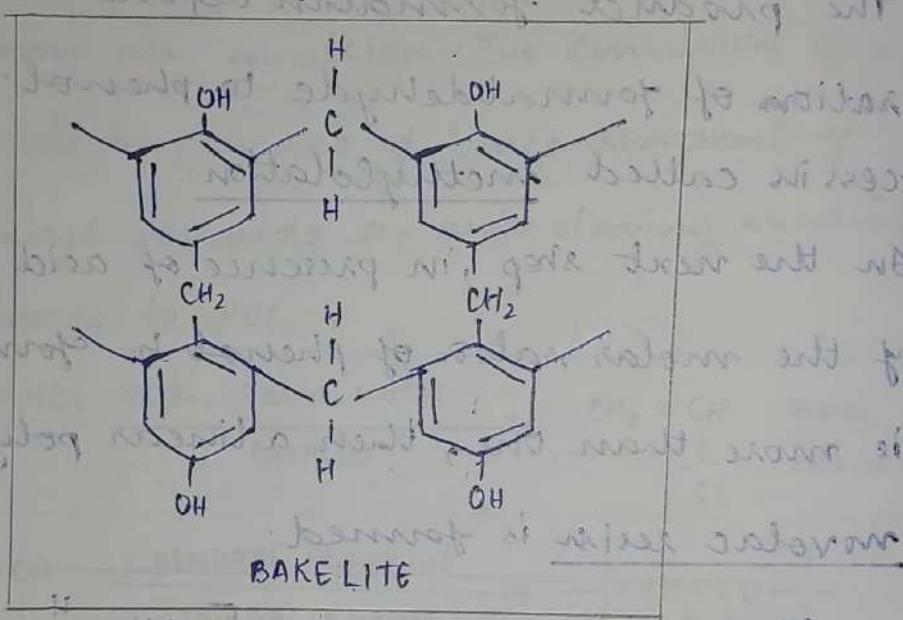


4. When novolac resin is further heated in presence of HCHO produces, i.e., hexa methylene diamine (curing agent) or cross-linked polymer Bakelite can be obtained.

→ These are rigid, hard, stain resistant, infusible and insoluble solids.

→ Though these have good chemical resistance, due to the presence of phenolic group (acidic) can react with alkalis.

→ These have good insulating properties and have resistance to heat and moisture.



→ Applications:

1. Manufacture of electrical appliances, handle

for cookware, molded articles for radio, television and telephone, as an adhesive for

grinding wheels, in ion exchange resins, in

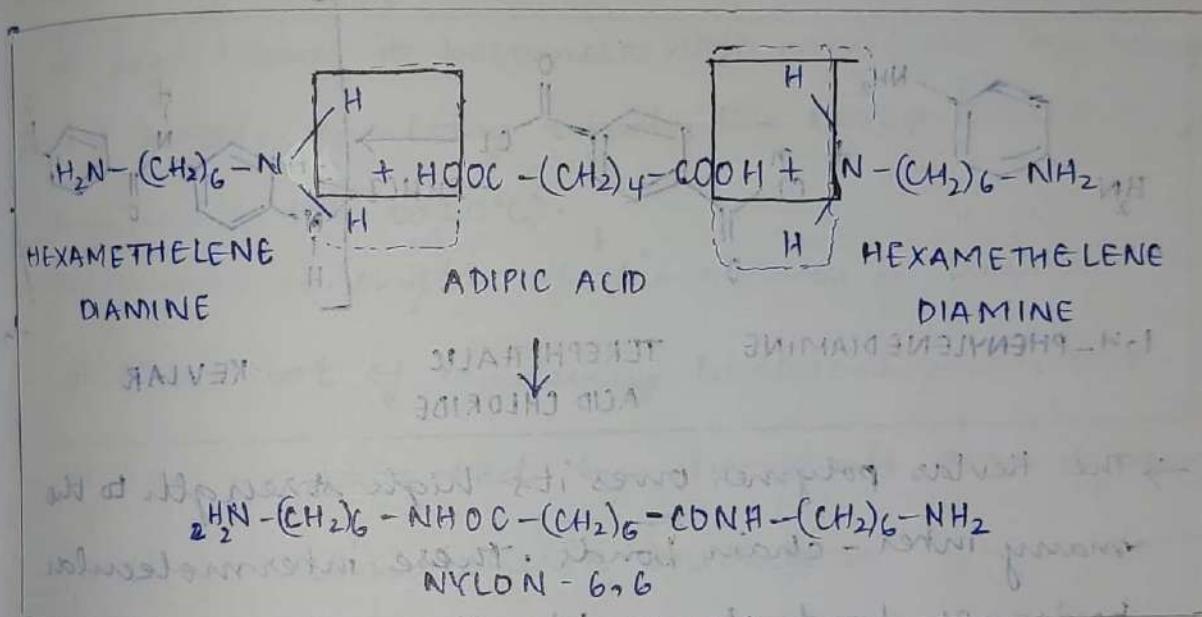
paints and varnishes, for the preparation of

beams of propeller shafts in paper industry

and in rolling mills.

→ Nylon - 6,6

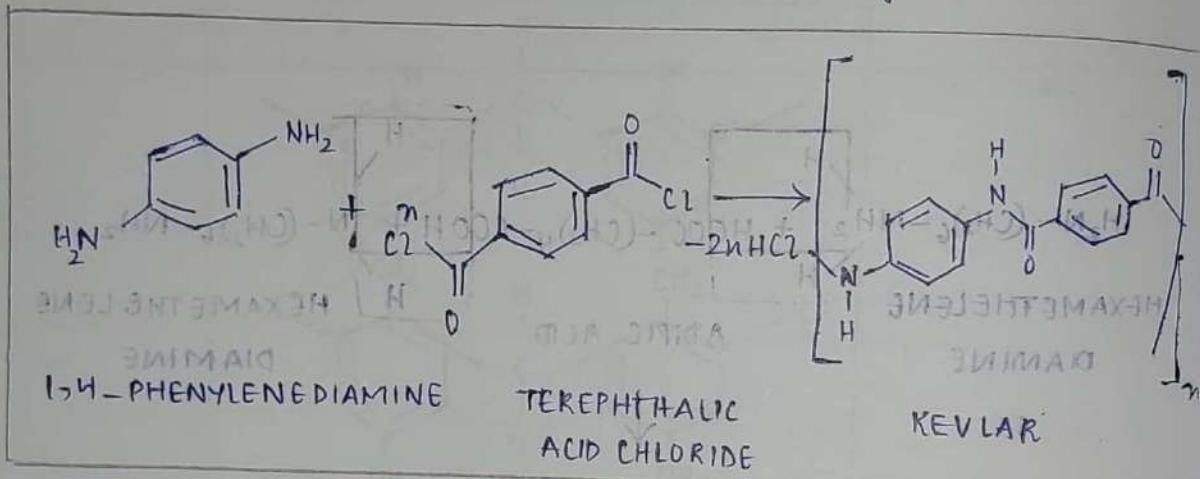
- These are synthetic polyamides formed by the repeated condensation reactions b/w acid and amine.
- The name of the compound reflects the number and types of carbon units taken part in the condensation.



- These are linear polymers bound by hydrogen bonding.
- These have high crystallinity, melting points, toughness, abrasion resistance, good mechanical strength and high flexibility. These are insoluble in solvents.
- Applications:
 - Manufacture of apparels, socks, carpets, flexible tubing of hair combs, insulating wires, bristles of tooth brushes and ropes etc.

→ Kevlar: Poly(Paraphenyleneterephthalamide) (PPTA) FIBERS

- 1 - It processes high tensile strength-to-weight ratio, a new lightweight strong fiber to use for light but strong materials.
- 2 - It is a condensed polymer prepared by the monomers 1,4-phenylene-diamine (para-phenylenediamine) and terephthaloyl chloride with the elimination of HCl as byproduct.



→ The Kevlar polymer owes its high strength to the many inter-chain bonds. These intermolecular hydrogen bonds form b/w the carbonyl groups and NH centers. Additional strength is derived from aromatic stacking interactions b/w adjacent strands.

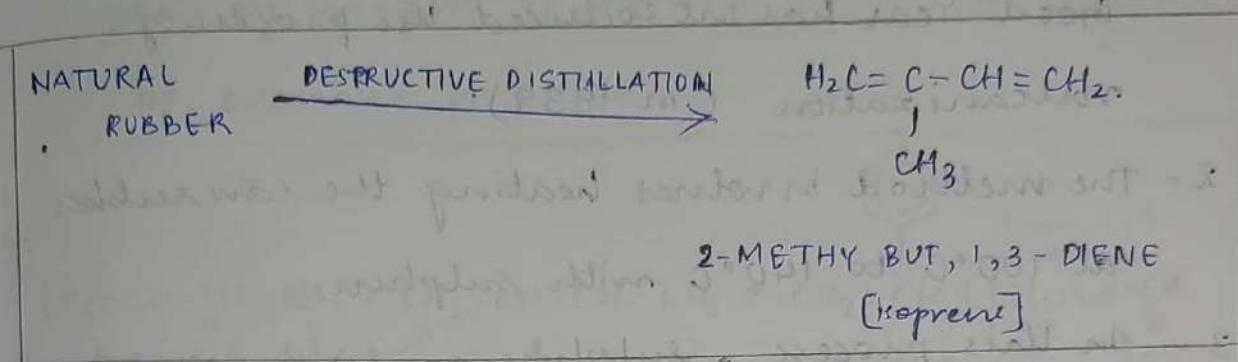
→ Kevlar maintains its strength and resilience down to cryogenic temperatures (-196°C); in fact, it is slightly stronger at low temperatures.

→ Applications:

- 1 - Spun into ropes or fabric sheets, as an ingredient in composite material components. Since it's five times stronger than steel; it is used for making bulletproof vests and bicycle wheels. Marine equipment.

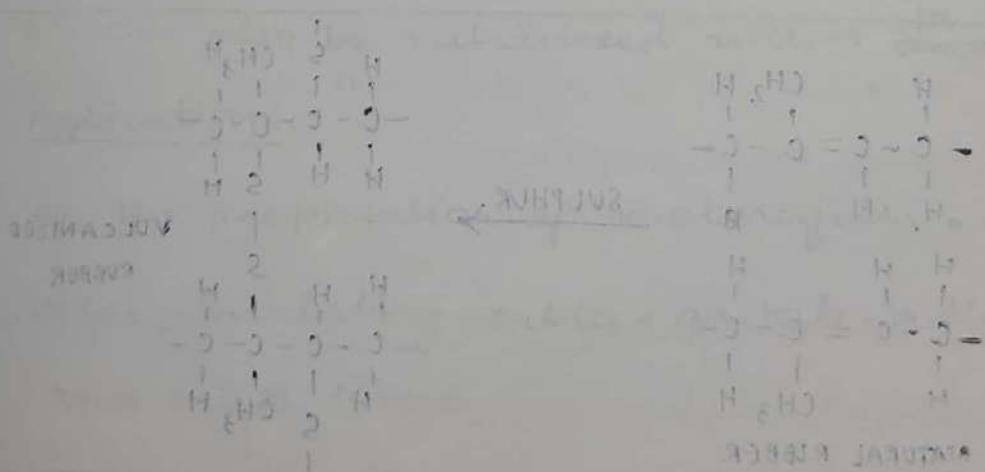
→ Rubber:

- 1- Natural rubber , chemically isoprene is 2-methyl 1,3-butadiene.



→ Natural rubber suffers from the following draw backs:

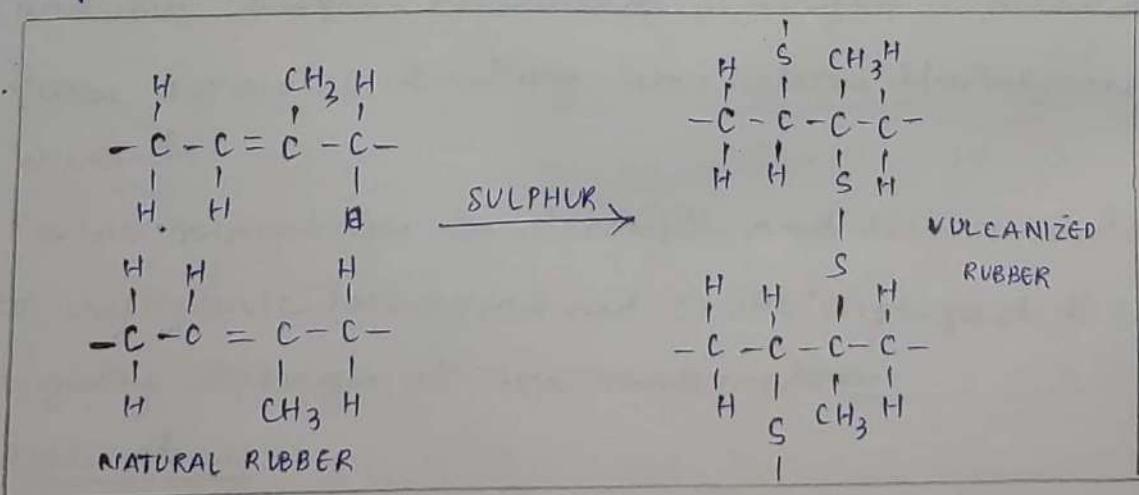
- At high temp. it becomes soft while at low temp. it is brittle. Resulting which, the temp. limit is limited (10°C to 60°C).
- The tensile strength of the rubber is low.
- It has a lot of tendency to absorb moisture.
- It can be attacked by chemicals and it can undergo atmospheric oxidation.



for the natural rubber and its properties are -
1) It is a polymer of alkene which is
addition to 1,3-butadiene.

→ Vulcanisation of rubber:

- 1 - In order to eliminate these drawbacks in raw rubber to improve workability, Charles Good Year has introduced the process of vulcanization (in 1839).
- 2 - The method involves heating the raw rubber at 100°C to 140°C with sulphur.
- 3 - In this process, sulphur combines with double bonds of different polyisoprene chains.
- 4 - As a consequence, due to the formation of sulphur bridges, the intermolecular movement of polymeric chains would be prevented.
- 5 - Depending on the % of S added, the extent of stiffness varies. Excess S leads to formation of hard rubber called ebonite.

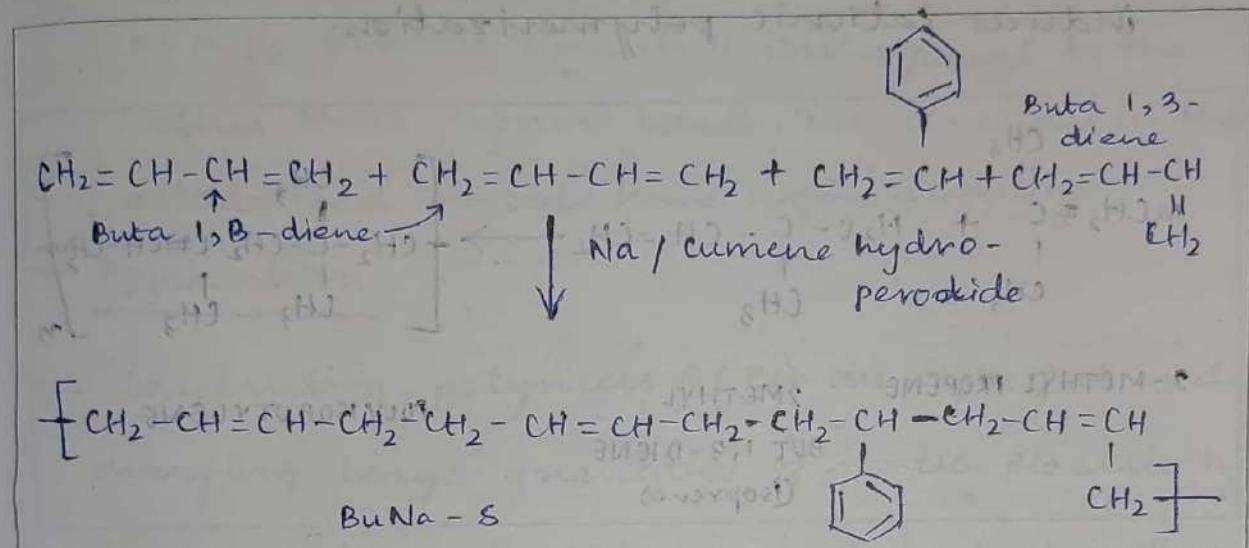


- G - An automobile tyre may contain 3 to 5% of rubber while ebonite (a battery case) may contain 30% of rubber.

→ BuNa - S (Styrene Rubber)

SYNTHETIC
ELASTOMERS

- i- It can be prepared by the copolymerization of 75% by weight of 1,3-butadiene and 25% by weight of styrene at 50°C in presence of cumene peroxide.

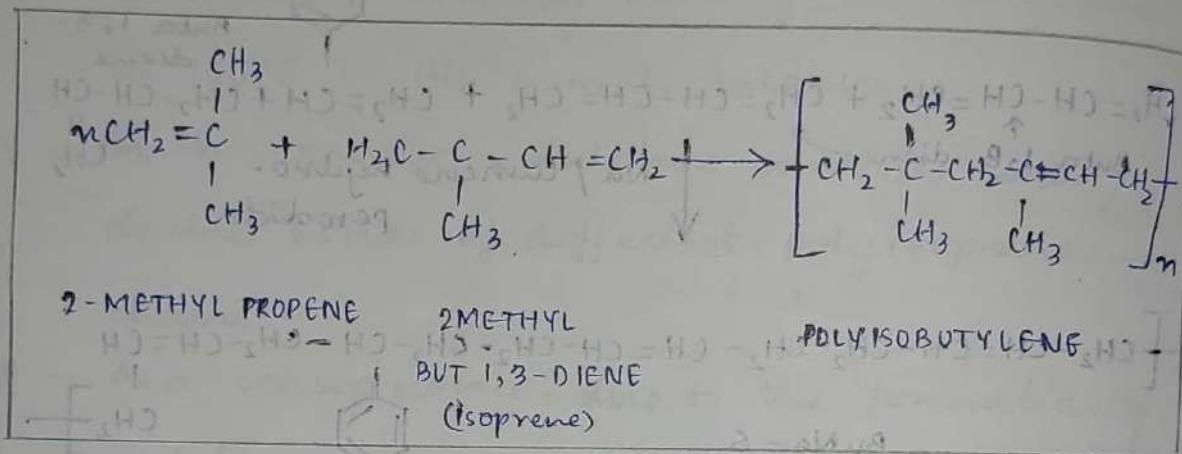


- It has similar properties like natural rubber in processing characteristics.
- It has good resistance, load bearing capacity and abrasion resistance.
- It has low oxidizing resistance and can swell in oils and solvents.
- It can also be vulcanized with S and S_2Cl_2 .
- Applications:

- 1- In the preparation of motorcycles, shoe soles, insulating cables, gaskets, adhesives, and tank liners.

→ Butyl Rubber:

- 1- It is poly isobutylene.
- 2- It can be prepared by co-polymerization of isobutene (97.5 to 99.5%) and isoprene (0.5 to 2.5%) in presence of AlCl_3 . The catalyst induces cationic polymerization.



- Due to low degree of unsaturation, it is oxidation resistant and extent of vulcanization is also less.
- It is least permeable to air and other gases.
- It is resistant to polar solvents but like alcohol, acetone and acidic chemicals (like HCl , HF , HNO_3 and H_2SO_4) but soluble in hydrocarbon solvents (Benzene).
- Due to non-polar nature, it has good electrical insulating property.
- Applications:
 - 1- For insulating high voltage wires and cables.
 - 2- Tubes for automobile tire treads.
 - 3- conveyor belts.
 - 4- lining the tanks.

Conducting Polymers

- Conducting polymers have backbones of continuous sp^2 hybridized carbon centers.
- One valence electron on each center resides in a p_z orbital, which is orthogonal to the other three sigma bonds. The electrons in these delocalized orbitals have high mobility.

Applications:

1. Conducting polymers (CPs) are useful in discharging large quantities of static electricity in computer industries and chemical industries. This can be accomplished by coating the conducting polymer over an insulating surface.
2. CPs can absorb harmful electromagnetic radiation. So these can be used to coat on the cases of computer monitors and cell phones.
3. Printed circuit boards are used in electrical and electronic instruments. They contain Cu coated epoxy resins which are expensive and have less adhesive nature. But polymer sheets coated with CPs are inexpensive and have better adhesive properties.
4. These are useful in the preparation of artificial nerves, i.e., biocompatible conductive polymers.

can be used for transmitting electrical signals in the body.

5- Artificial intelligent materials: These are also called as smart materials. The interesting aspects of these materials is that they can remember configuration and can confirm when exactly same stimulus is given. This property can be utilized in generating passwords where high security is required.

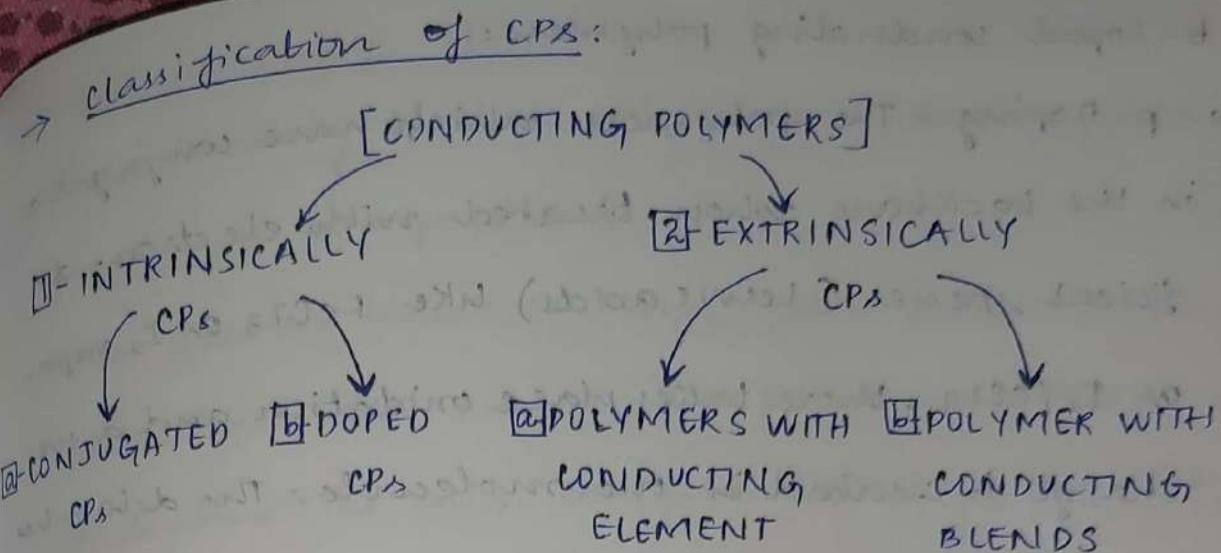
6- These are useful in detecting the gases.

7- Polymer rechargeable batteries: Repeated oxidation and reduction of polymeric backbone constituents is the principle of polymer rechargeable batteries.

8- These are useful as corrosion inhibitors.

9- These can be applied in Flat Panel Displays (less than 2mm thick) which are thinner than liquid crystals displays or plasma displays.

10- These are also useful as Flexible Display Devices for mobile phones.



1- intrinsically conducting polymers:

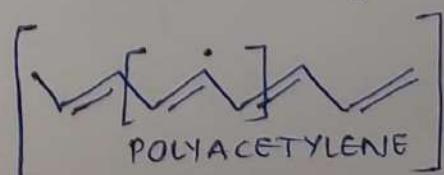
The conduction of electricity in this type of polymers is due to conjugation in the backbone of the polymer. The conjugation can be due to either pi electrons or due to doped ingredients.

a- Conjugation due to conjugated pi-electrons in the backbone:

In these types of polymers, due to the presence of double bonds and lone pair of electrons, conduction of electricity takes place.

Actually due to overlapping of conjugated pi-electrons, there develops valence and conduction band throughout the backbone of the polymer. Electrical conduction can occur only after attainment of required energy of activation either thermally or photo chemically.

Ex: Polyaniline, polyacetylene



b-Doped conducting polymers:

i-p-Doping - The polymers which have conjugation in the backbone, when treated with electron-deficient species (Lewis acids) like FeCl_3 or I_2 vapour or I_2/CCl_4 , there takes place oxidation and a +ve charge is created in the molecule. The delocalization of +ve charges creates electrical conduction.

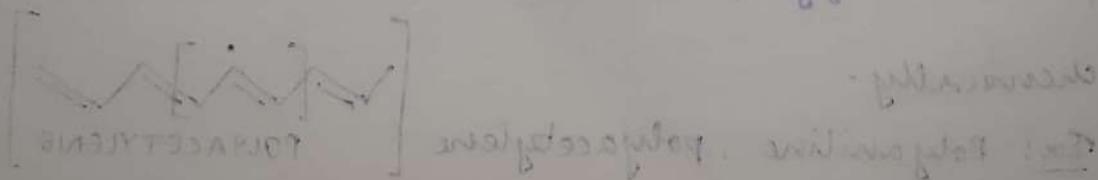


ii-n-Doping - Lewis bases are treated with polymers having conjugation.

→ Intrinsically conducting polymers are charac-

- characterised by good electrical conductivity
- capability to store charge
- capacity to exchange ions
- ability to absorb visible radiation thereby yielding the coloured compounds.
- X-ray transparent

and applications to its medical applications, even
insects, recycling and for insulation and transportation
also communication with a fibre optics and microfibres
also pollutants and molecules to remove them



b- Extrinsically CPs:
the conductivity of these polymers is due to addition of external ingredients.
When carbon blacks or some metal oxides or metallic fibers are added, the polymer becomes conductive. The min. concentration of the element required for the conductivity is called percolation threshold. The filler ingredients:

that percolate have more surface area, more porosity and filamentous nature due to which they can enhance the CPs.

Individually pristine I carbon and no additive conduct

A nanotube filled ribbon of no carbon will

conductivity resulting no current is nanotube

conductivity of individual tube no power source exist

so nanotube exist and an electric circuit is formed

because exist exist current flow exists and disturbance

will exist therefore if structure no resistive exist (conduct)

therefore it is conducting & resulting current direction also

current direction is same with direction of the

polymer chain

→ Mechanism of conduction in Poly Acetylene:

POLY ACETYLENE:

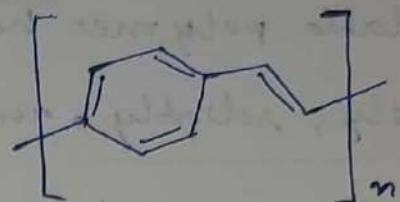
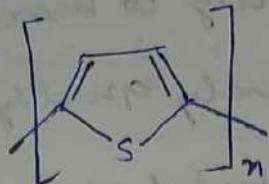
PA consists of chains of hundreds to thousands of C atoms linked by alternating single and double bonds. Conductivity of pure polyacetylene is about $4.4 \times 10^{-5} \text{ S/cm}$. Upon doping with oxidizing agents like sodine, the conductivity increases to about 400 S/cm .

When the oxidative dopant such as sodine is added, it takes away an electron from the π -backbone of the PA chain and creates a positive center (hole) on one of the carbons. The other π -backbone electron resides on the other C making it a radical.

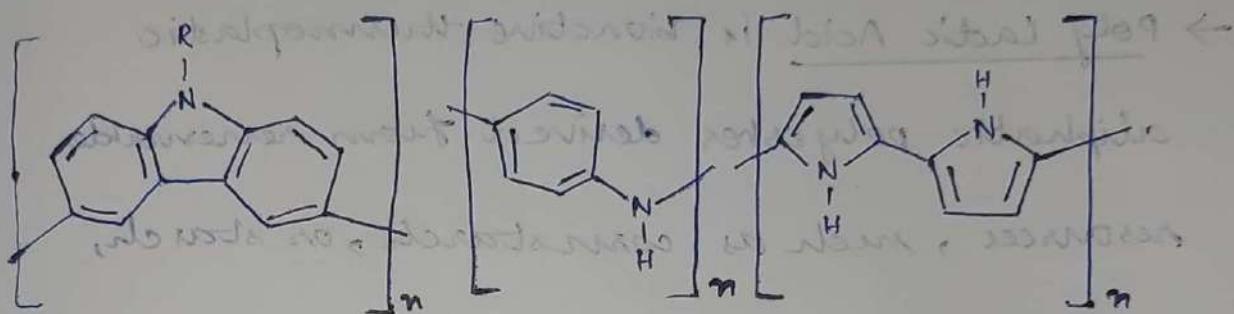
The radical ion formed is called Polaron. A dipolaron is formed on further oxidation.

Then these migrate and combine to establish a backbone double bond. As the two electrons are removed, the chain will have two hole centers (holes). The chain as a whole is neutral, but holes are mobile and when a potential is applied they migrate from one C to another and account for conductivity.

→ Examples of CPs:



POLYTHIOPHENE - POLYPARAPHHENYLENEVINYLENE



→ They have many advantages as compared to the

non-conducting polymers:

- 1- Used in artificial muscles
- 2- Fabrication of electronic devices
- 3- Solar energy conversion
- 4- Rechargeable batteries and sensors.
- 5- Super capacitors
- 6- Light Emitting Diodes (LEDs).
- 7- Solar cells
- 8- Field effect transistor (FET)
- 9- Biosensors.

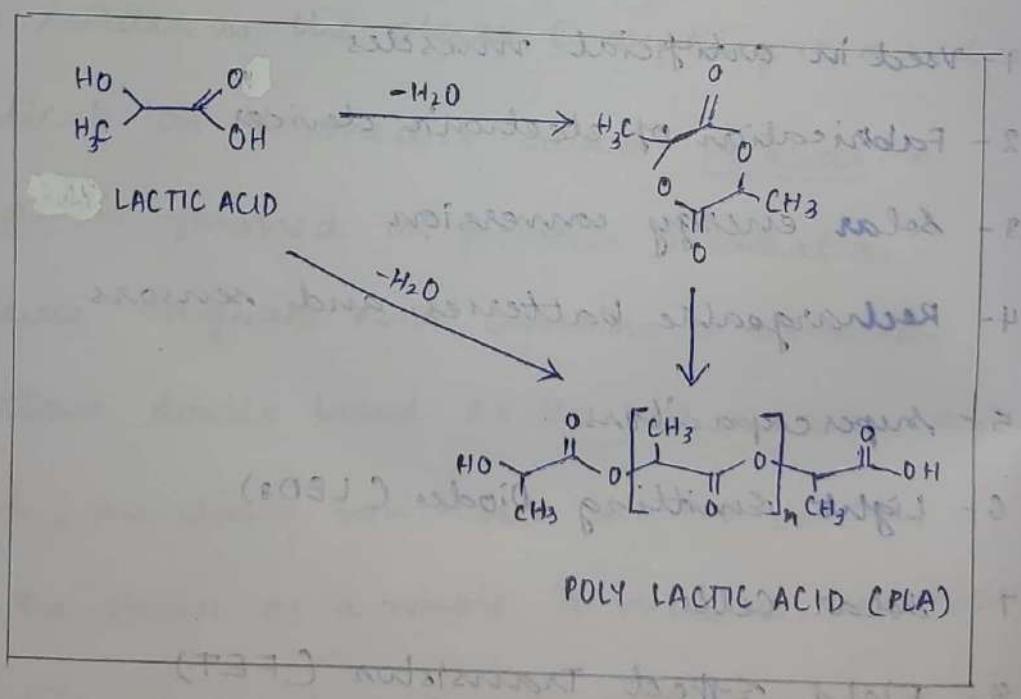
→ Biodegradable-polymers:

A biodegradable polymer has the ability to break down, safely, reliably, and relatively quickly, by biological means into raw material of nature, and disappear into nature.

→ Poly Lactic Acid is bioactive thermoplastic

aliphatic polyesters derived from renewable resources, such as cornstarch, or starch, or sugarcane.

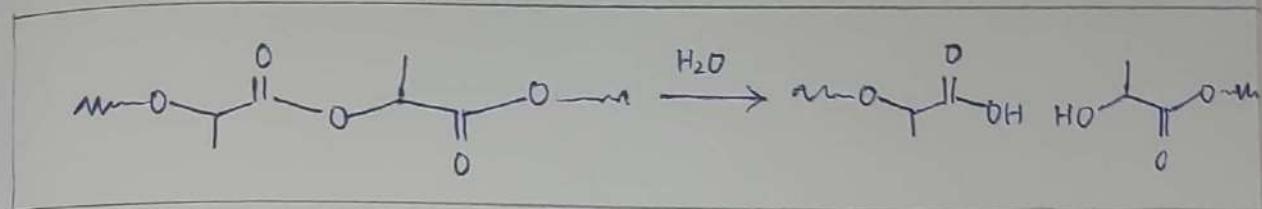
Another route to PLA is the direct condensation of lactic acid polymers monomers. This process needs to be carried out at less than 200°C.



→ Degradation Mechanisms:

- enzymatic degradation

- Hydrolysis



11 Mar
Wed

Fuels

A Fuel is a chemical substance which undergoes ~~can~~ ~~can~~ combustion to produce heat. Heat produced is utilized for various purposes which include industrial, domestic purposes.

The principle elements which are invariably present in any fuel are C and H which on combustion produce CO_2 and H_2O along with heat.



→ Classification of fuels:

Based on the physical state and availability, fuels are classified into

PHYSICAL STATE	PRIMARY FUELS (Natural)	SECONDARY FUELS (derived)
SOLID	WOOD, COAL	cotle, desined forms of coal
LQUID	CRUDE OIL	diesel, gasoline
GASEOUS	NATURAL GAS	producer gas, water gas.

→ Ranking of coal:

[wood → coal → peat → lignite → bituminous
coal]

→ Anthracite

← Moisture content, H, O, N, S, volatile matter content

→ calorific value, hardness

* → Characteristics of a good fuel:

A good fuel will have the following characteristics.

1 - High calorific value.

2 - Moderate ignition temperature.

3 - Low moisture content.

→ does not have any calorific value.

4 - Low ash content.

5 - No harmful combustible products.

6 - Combustion control.

7 - Ease of availability.

8 - Ease of storage and transportation.

→ Calorific value is the amount of heat given
(unit mass of fuel)
out by a fuel when it is burnt completely
in presence of air or oxygen.

Units: cal/gm, kcal/kg, B.Th.U/ft³

C.H.U/vol.

British Thermal
units

Centigrade Heat Units.

$$[1 \text{ B.Th.U} = 252 \text{ cal}]$$

→ HCV / GCV - Higher calorific value (a) Gross

calorific value is the amount of heat given
(unit mass of fuel)
out by a fuel when it is burnt completely

in presence of air or O₂. Products are allowed
to cool down to room temperature.

→ LCV / NCV - Lower CV (b) Net CV is the

amount of heat given out by a fuel when
it is burnt completely in presence of

air or O₂. Products are allowed to escape.

$$LCV = HCV - \left[\frac{\text{Mass of H in fuel}}{9} \times 587 \right] \downarrow \begin{matrix} (\text{kcal/kg}) \\ \text{latent heat of steam} \end{matrix}$$

→ Bulong's formula:

$$HCV = \frac{1}{100} \left\{ 8080C + 34500 \left[H - \frac{O}{8} \right] + 2240S \right\} \text{ kcal/kg}$$

$$[LCV = HCV - 0.09H \times 587] \text{ kcal/kg}$$

Q) A coal has following ultimate analysis:

$$C = 84\%, S = 1.5\%, N = 0.6\%, H = 5.5\%, O = 8.4\%$$

Find Gross and Net CV with the help of

Bulong's formula.

$$\text{(a) } HCV = \frac{1}{100} \left[8080(84) + 34500 \left(5.5 - \frac{8.4}{8} \right) + 2240(1.5) \right]$$

$$= 8356.05 \text{ kcal/kg}$$

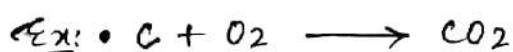
$$\text{Net CV} = HCV - 0.09(5.5) \times 587 = 8356.05 - 290.565$$

$$= 8065.485 \text{ kcal/kg}$$

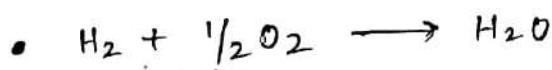
* Combustion Calculations:

12 Mar
Thur

1 - Substances always combine in definite proportions. These definite proportions can be determined by molecular mass of elements combining and products formed.



12 g of C requires 32 g of O to produce 44 g of CO_2



2 g of H requires 16 g of O to produce 18 g of H_2O .

2 - 22.4 lit of any gas at STP has mass equal to its 1 mole.

3 - Air contains 21% of O by volume and 23% of O

by mass.

4 - (theoretical amount of O_2 required) -

(O_2 present in fuel) gives O_2 required for (air)

complete combustion of fuel.

* - Molecular mass of air is taken as 28.94 g/mol

5 - Mass of air required (considering 23% of O by

mass in air)

$$\text{Mass of air} = \frac{100}{23} \left[\frac{32C}{12} + \frac{16H}{2} + \frac{32S}{32} - O \right]$$

6- Mass of any substance or gas can be converted into its volume by using gas equation

$$[PV = nRT]$$

Q) Calculate mass and volume of air required for combustion of 1 kg of C

(a) Mass of air = $\frac{100}{23} \times \frac{32G}{12}$

$$= \boxed{11594.2029 \text{ g}}$$

- 11594.2029 g in moles is $\frac{11594.2029}{28.94}$

1 mol air = 400.628 mol

1 mol $\rightarrow 22.4 \text{ lit}$

400.628 mol $\rightarrow ?$

$$22.4 \times 400.628 = \boxed{8974.0672 \text{ lit}}$$

Q) A sample of fuel contains the following by weight.

$$C = 81\% ; H = 4\% ; O = 2\% ; N = 10\% ; S = 1\%$$

remaining is ash. Calculate volume of air

required for perfect combustion of 1kg of

fuel assuming STP conditions.

$$\text{Mass of air} = \frac{100}{23} \times \frac{c}{32} \times 810$$

(sol) Given $c = 810 \text{ g}$

$$H = 40 \text{ g}$$

$$O = 20 \text{ g}$$

$$N = 100 \text{ g}$$

$$S = 10 \text{ g}$$

$$\text{Mass of air} = \frac{100}{23} \left[\frac{32c}{12} + \frac{16H}{2} + \frac{32S}{32} - O \right]$$

$$= \frac{100}{23} \left[\frac{32(810)}{12} + \frac{16(40)}{2} + \frac{32(10)}{32} - 20 \right]$$

$$= \boxed{10739.130 \text{ g}}$$

Mass of air in moles is $\frac{10739.130}{28.94}$

$$= 371.082 \text{ mol}$$

$$1 \text{ mol} \rightarrow 22.4 \text{ lit}$$

$$371.082 \text{ mol} \rightarrow ?$$

$$\Rightarrow 371.082 \times 22.4 = \boxed{8312.236 \text{ lit}}$$

Q) Calculate wt. of air required for complete combustion of 5kg of coal containing 80% C, 15% H and the rest O.

Sol) 5 kg of coal contains
 $C = 80\% \rightarrow 4000g$

$H = 15\% \rightarrow 750g$

$O = 5\% \rightarrow 250g$

$$\text{Mass of air} = \frac{100}{23} \left[\frac{32C}{12} + \frac{16H}{2} + \frac{32S}{32} - O \right]$$

$$= \frac{100}{23} \left[\frac{32 \times 4000}{12} + \frac{16 \times 750}{2} + \frac{32 \times 250}{32} - 250 \right]$$

$$= \boxed{71376.811g}$$

Q) A furnace oil contains 80% C, 20% H, by weight of. Determine wt. of air req. per kg of oil, if 20% excess air is used for complete combustion?

Sol) $C = 800g$

$H = 200g$

$$\text{Mass of air} = \frac{100}{23} \left[\frac{32(800)}{12} + \frac{16(200)}{2} \right]$$

$$= 16.231 \text{ kgs}$$

20% excess air is supplied

$$16.231 \times \frac{120}{100} = 19.477 \text{ kg}$$

Q) Calculate the NCV of the fuel of coal sample having the following

[14 Apr]

Tues

Composition: C = 80%; H = 5%; O = 4%

N = 3%; S = 3.5%; ash 5%

Sol) $HCV = \frac{1}{100} [8080C + 34500\left(H - \frac{O}{8}\right) + 2240S]$

$$HCV = 8094.9 \text{ cal/g}$$

$$LCV(\text{or}) NCV = [HCV - 0.09H \times 587]$$

$$LCV = 8094.9 - 0.09(5) \times 587$$

$$LCV = 7830.75 \text{ cal/g} \quad 4.1\% \text{ H}$$

Q) A coal contains 62.4% C; 6.9% O; 1.2% N; 0.8% S. Calculate wt. of air required.

Sol) Mass of air = $\frac{100}{23} \left[\frac{32C}{12} + \frac{16H}{2} + \frac{32S}{32} - O \right]$

$$\text{Mass of air} = 839.56 \text{ g}$$

16 Apr.
Thurs

* Analysis of coal: The coal should be analyzed to assess its quality. It is done by two methods:

- 1 - Proximate analysis.
- 2 - Ultimate analysis.

* PROXIMATE ANALYSIS: This analysis records moisture, volatile matter, ash and fixed carbon as percentages of original weight of coal sample. The analysis is significant in commercial classification and industrial utilization of coal.

It is a quantitative analysis of following determinations:

- 1 - Moisture content - About 1g of finely powdered air dried coal sample is weighed in a crucible and is placed inside an electric hot air oven maintained at $105-110^{\circ}\text{C}$. It is kept for one hour and then taken out. It is cooled in a desiccator and weighed. The loss in wt. is reported as the moisture content on % basis.

$$\boxed{\% \text{ of moisture} = \frac{\text{loss in wt. due to loss in water moisture}}{\text{weight of coal sample taken}} \times 100}$$

2 - Volatile matter - The moisture free coal is taken in a silicate crucible and heated for

- ~ 7 mins. in a muffle furnace at $950^{\circ}\text{C} \pm 20^{\circ}\text{C}$.
- The crucible is taken out and cooled first in air and then in desiccators. The loss in wt. is reported as volatile matter on % basis.

$$\boxed{\% \text{ of volatile matter} = \frac{\text{loss in wt. due to volatile matter}}{\text{wt. of coal sample taken}} \times 100}$$

3 - Ash content - It is the weight of residue obtained after burning a weighed amount of dry coal and in an open crucible at $700 - 750^{\circ}\text{C}$ for half an hour in a muffle furnace. The wt. of residue remaining in the crucible is reported as ash content on % basis.

$$\boxed{\% \text{ of ash} = \frac{\text{wt. of ash formed}}{\text{wt. of dry coal taken}} \times 100}$$

4 - Fixed Carbon - It is the quantity of carbon in coal that can be burnt by a primary current of air drawn through the hot bed of fuel.

The sum total of the %s of moisture, volatile matter and ash subtracted from 100 gives the

$$\left\{ \begin{array}{l} \% \text{ of fixed carbon} = 100 - \% \text{ of } \\ \quad \text{moisture} \\ \quad + \text{volatile} \\ \quad \text{matter} + \text{ash} \end{array} \right\}$$

→ significance of proximate analysis: It provides the following valuable information.

in assessing the quality of coal:

- 1 - Moisture Content - Moisture lowers the effective calorific value because considerable amount of heat is wasted in evaporating the moisture during combustion. Hence lesser the moisture content, better the quality of coal as a fuel.

- 2 - Volatile matter - It may be combustible gases (CH_4 , CO_2 , CH_4 , etc) or non-combustible gases (CO_2 , NO_2).

- The presence of non-combustible gases is undesirable since they do not add to the

- heat value. The volatile matter content of coal influences the furnace design.
- Higher the content, larger is the combustion space required. The % of volatile matter in coal denotes the proportion of coal which will be converted into gas and tar products by heat.
- Hence high volatile matter content is preferable in coal gas manufacture and carbonization process plants.
- Low volatile matter and high fixed C is preferred for manufacture of metallurgical coke.

3 - Ash -

- It is non-combustible, useless matter that is left behind when all the combustible matter is burnt off from coal.
- Hence lesser the ash content better is the quality of coal.

4 - Fixed Carbon -

- Higher the % of fixed C, greater is the calorific value and better the quality of coal.

* ULTIMATE ANALYSIS OF COAL: This is the elemental analysis. It involves the determination of C and H, N, O and S.

1 - C and H: About 1-2g of accurately weighed coal sample is burnt in a current of P_2O_5 in a combustible apparatus. The C and H of the sample are converted into CO_2 and H_2O . These are absorbed by KOH and $CaCl_2$ tubes of known wts. The wts. of $CaCl_2$ and KOH in the bulbs are determined. The increase in wt. of $CaCl_2$ gives the wt. of H_2O formed and increase in wt. of KOH gives the wt. of CO_2 formed.

$$C\% = \frac{\text{Increase in wt. of KOH} \times 12 \times 100}{\text{wt. of coal sample taken}}$$

$$H\% = \frac{\text{Increase in wt. of } CaCl_2 \times 2 \times 100}{\text{wt. of coal sample} \times 18}$$

Significance:

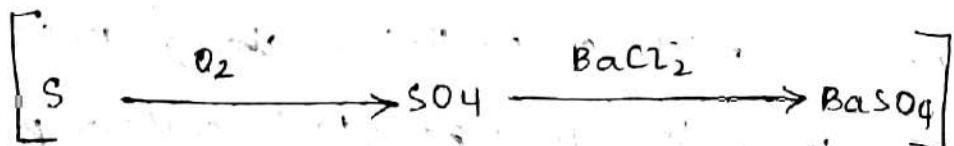
- Greater the % of C and H, better is the coal in quality and calorific value.

2 - N: The N in coal is determined by Kjeldahl method. About 1g of weighed powdered coal

is heated with conc. H_2SO_4 along with K_2SO_4 and $CuSO_4$ in a long necked flask called a Kjeldahl's flask. After the solution becomes clear i.e., when whole N is converted into ammonium sulphate $[(NH_4)_2SO_4]$, it is treated with excess of NaOH to liberate NH_3 . The liberated NH_3 is distilled into a measured amount of standard acid solution. The unused acid is then determined by titrating with standard NaOH soln. Thus the amount of acid neutralized by liberated NH_3 is determined. From this, the N present in the sample is calculated.

$$N\% = \left[\frac{\text{Vol. of acid used} \times \text{Normality of acid} \times 14}{\text{wt. of coal sample} \times 1000} \times 100 \right] \%$$

3 - S - It is determined from the washings obtained from the known mass of coal used in a bomb calorimeter for determination of calorific value. During this, S is converted into sulphate (SO_4). The washings are treated with $BaCl_2$ solution and thus $BaSO_4$ is precipitated. The ppt is filtered, washed and heated to const. wt.



$$\left[\frac{\% \text{ of } BaSO_4 \text{ obtained}}{\text{wt. of coal sample} \times 233} \right]$$

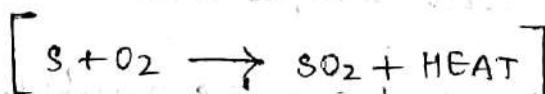
N - O - It is determined indirectly by deducting the combined % of C, H, N and S from 100.

$$\left[\% = 100 - \% \text{ of } (C + H + S + N) \right]$$

significance :

N - It has no calorific value and hence its presence is not desirable.

S - S adds to the calorific value of coal since the oxidation of S is an exothermic process.



- But SO_2 is harmful because it gets oxidized to SO_3 , which forms H_2SO_4 leading to corrosion.

O - The O content in coal decreases the calorific value. Hence a good quality coal should have low % of O.

Q) A coal sample was analysed as follows:

17 Apr
Fri

exactly 2.5g was weighed into silica crucible. After heating for one hour at 110°C, the residue weighed 2.415g, the crucible was then covered with a vented lid and strongly heated for exactly seven min. at 950 ± 20°C. The residue wt. 1.528g. The crucible was then heated without cover at 700°C until a constant wt. was obtained. The last residue was found to weight 0.245g. Calculate the % results of above analysis.

i - % moisture :

$$\text{wt. of coal} = 2.5 \text{ g}$$

$$\text{Mass of moisture in coal sample} = 2.5 - 2.415$$

$$= 0.085 \text{ g}$$

$$\% \text{ of moisture} = \frac{W_1 - W_2}{W_1} \times 100$$

$$= \frac{0.085}{2.5} \times 100 = 3.4\%$$

ii - Determination of % volatile matter:

$$\text{Mass of volatile matter} = 2.415 - 1.528$$

$$= 0.887 \text{ g}$$

$$\% \text{ of volatile matter} = \frac{0.881 \times 100}{2.5} = 35.48\%$$

iii - Determination of % Ash:

Mass of residue = 0.245

$$\% \text{ of ash} = \frac{0.245}{2.5} \times 100 = 9.8\%$$

iv - Determination of fixed carbon:

% of fixed C = 100 - [% of moisture + volatile

matter + ash]

$$= 100 - [3.4 + 35.48 + 9.8]$$

$$= 100 - 48.68 = \boxed{51.32\%}$$

* Fractional Distillation of Crude Oil:

According to modern theory, petroleum has resulted from the partial decomposition of marine animals and vegetables, organisms of pre-historic times.

Refining is defined as - the process, by which

points and their further petroleum is made

free of impurities; division of petroleum into different fractions having different B.P.s. and their

further treatment to impart specific properties.

The average composition of crude oil:

$$\left[\begin{array}{l} \text{C} = 79.5 - 87.1\% \\ \text{H} = 11.5 - 14.8\% \\ \text{S} = 0.1 - 3.5\% \\ \text{N+O} = 0.1 - 0.5\% \end{array} \right]$$

→ The process of refining involves:

- 1- Removal of solid impurities: The crude oil is a mixture of solid, liquid and gaseous substances.
- This is allowed to stand for sometimes so that the heavy solid particles settle down and the gases evaporate.

- The supernatent liquid is then centrifuged and all the solids get removed.

2- Removal of water (Cottrell's process):

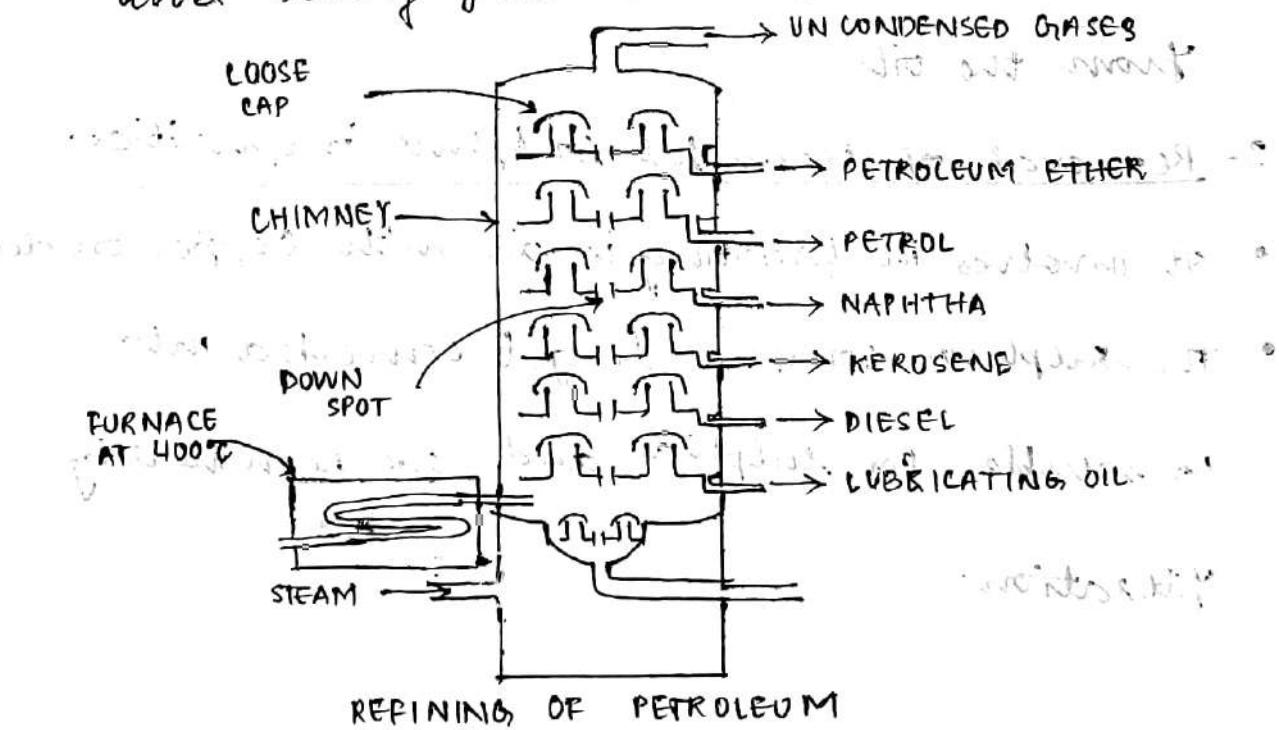
- The crude oil well is a stable emulsion of oil and salt water.
- The mixture is passed b/w two highly charged electrodes so that the emulsion films are destroyed and the colloidal water droplets combine into bigger drops and separates out from the oil.

3- Removal of harmful sulphur impurities:

- It involves in treating in oil with copper oxide.
- The sulphur compounds get converted into insoluble Cu₂S and are removed by filtration.

4- Fractional Distillation:

- the crude oil is then heated to about 400°C in an iron retort in which all the volatile constituents are evaporated.
- the hot vapours are then passed into a fractioning column.
- it is a tall cylindrical tower containing a number of horizontal stainless steel trays at short distances.
- each tray is provided with a small chimney covered with a loose cap.
- As the vapours go up, they become cool and fractional condensation takes place at different heights of column.
- Higher boiling fractions condense first and lower boiling fractions later.



The fractionation products are:

1- uncondensed gases:

- lower hydrocarbons
- obtained below 30°C
- highly combustible.
- domestic fuel.

2- Gasoline or petrol:

- C5 to C8
- obtained b/w $40 - 120^{\circ}\text{C}$.

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2021

- C.V. is 11,250 Kcal/Kg.
- highly volatile and inflammable
- fuel for internal combustion engines.

3- Kerosene oil

- C10 to C16
- obtained b/w $180 - 250^{\circ}\text{C}$
- C.V. is 11,100 Kcal/Kg.

Properties - domestic fuel, tractor fuel, and
jet engine fuel, and for
making of oil gas.

4- Gas oil or diesel oil:

- C15 to C18
- obtained b/w $250 - 320^{\circ}\text{C}$
- C.V. is 11,000 Kcal/Kg.
- diesel engine fuel.

5 - Residual oil:

- on cooling, gives paraffin wax, greases and lubricating oil, asphalt
- used for manufacture of candle, polishes, paper, etc. lubricants, preservatives for wood proofing and laying down the roads, respectively.

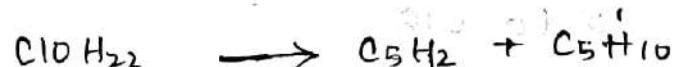
* Cracking:

21 Apr
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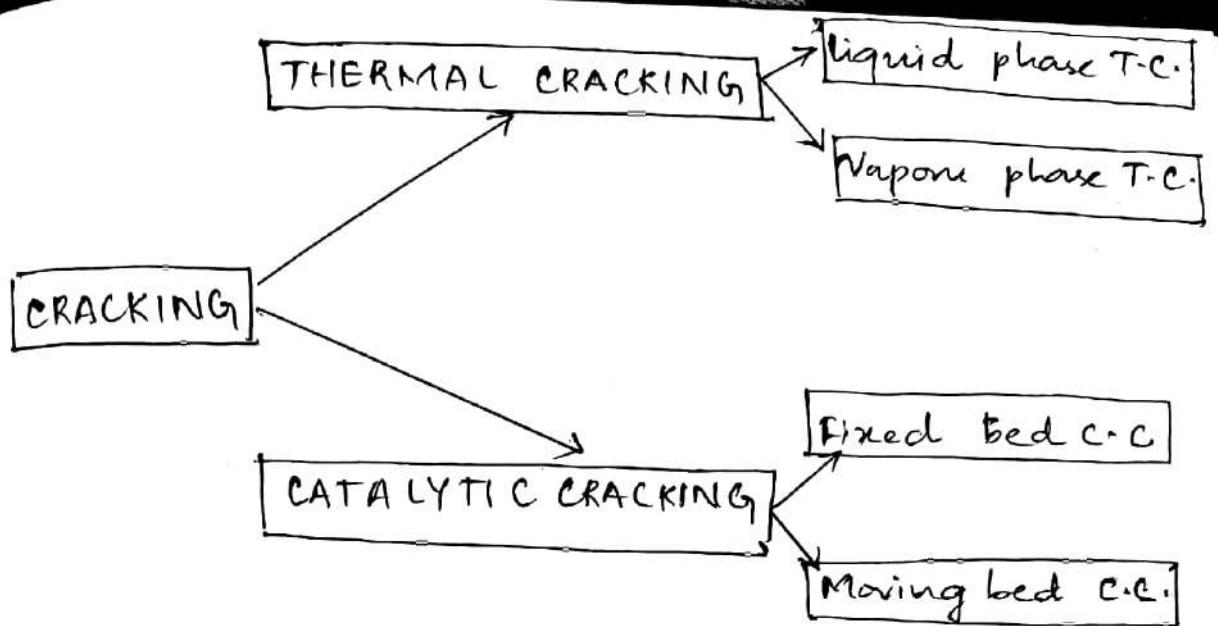
During distillation of crude oil, the gasoline obtained is of very importance in automobile industry. The yield and quality of gasoline is improved by cracking. It involves thermal decomposition of heavier fractions.

Cracking is defined as the process by which the higher hydrocarbons are decomposed into lower hydrocarbons by the application of heat.

Ex: $C_{10}H_{22}$ cracks into paraffinic and olefinic hydrocarbons:

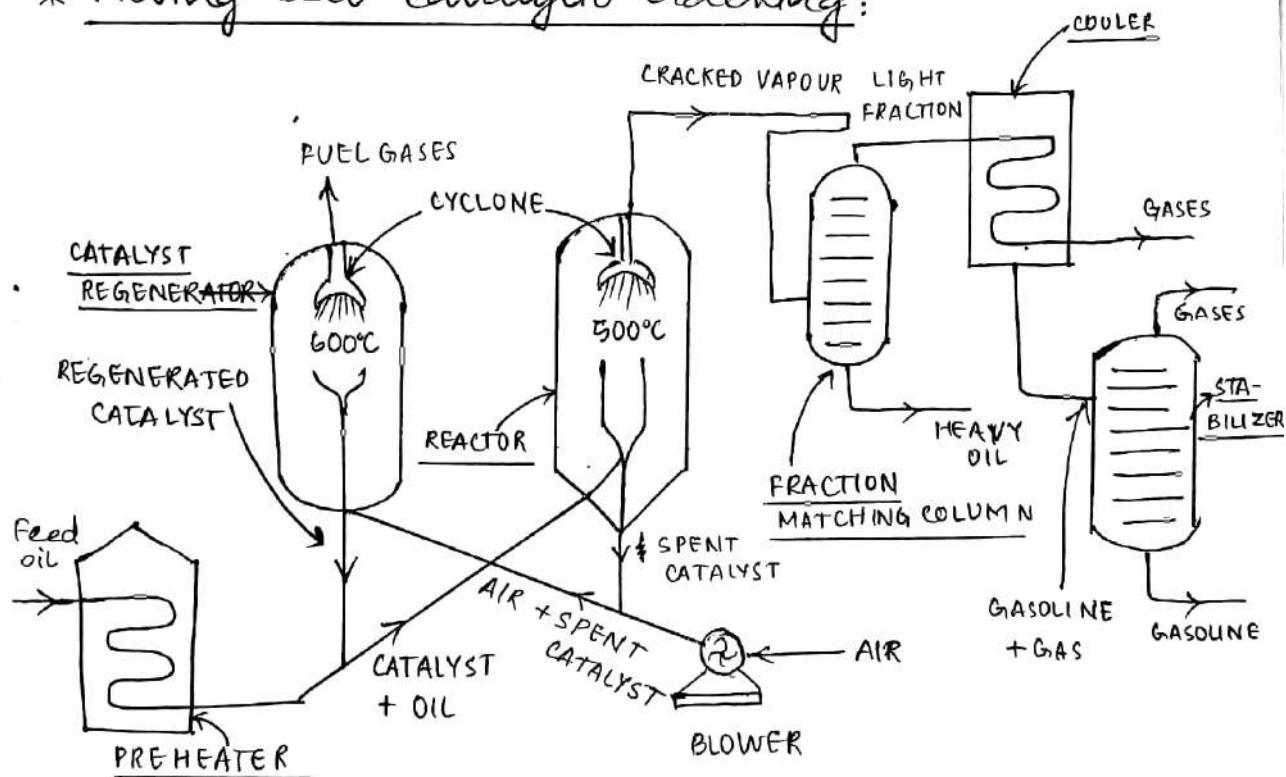


Decane Paraffin Olefin
(Pentane) (Pentene)



→ In C.C., the catalyst is Artificial clay added to ZnO.

* Moving bed catalytic cracking:



Moving bed catalytic cracking is also known as fluidised bed catalytic cracking process.

* KNOCKING :

- In an internal combustion engine, a mixture of gasoline vapors and air is used as fuel.
- After initiating the combustion reaction, the flame should spread rapidly through the gaseous mixture. Thus the expanding gases push the piston down the cylinder.
- The ratio of the gaseous volume in the cylinder at the end of induction stroke to the volume at the end of compression stroke of the piston is called compression ratio. It indicates the extent of compression of fuel-air mixture by piston.
- The efficiency of an internal combustion engine increases with increase in compression ratio.
- When the fuel-air mixture gets ignited instantaneously, it produces sound in the engine called as knock. The rattling noise produced in the internal combustion engine is called knocking. It is due to:
- Faulty design of engine,
 - Unfavorable conditions due to defective ignition of fuel-air mixture.

→ Tendency of fuel constituents to knock:

[straight chain paraffins > branched chain paraffins > olefins > cycloparaffins > aromatics]

* Petrol Rating:

- The performance of gasoline in an internal combustion engine is rated based on octane no. Higher the octane no. of fuel, better is its performance and lower is the knocking engines.
→ The Octane number of gasoline is defined as the percentage of iso-octane present in a mixture of iso-octane and n-heptane.
- Eg: The octane number of a motor fuel is 80. It means that the gasoline will produce knocking by the mixture of 80 parts of iso-octane and 20 parts of heptane.

- n-heptane knocks very badly and its anti-knock value is arbitrarily zero.
- Isooctane has the highest anti-knocking value (100).

- Improvement of anti-knock characteristic of a fuel: The octane number of fuel can be raised by addition of certain compounds:

- Tetra ethyl lead $[(C_2H_5)_4Pb]$ or TEL.
- Diethyl Telluride $[(C_2H_5)_2Te]$.

These are anti-knock compounds and the process of adding these compounds is called.

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23 April
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* Diesel engine:

- In diesel engines, the fuel is exploded by the application of heat and pressure. Diesel engine fuels consist of longer chain hydrocarbons than internal combustion engine fuels.
- The main characteristic of a diesel engine fuel is that it should ignite below compression ratio temperature and there should be as short an induction lag as possible.

→ Cetane number:

The knocking characteristics of diesel oil are given by cetane number which is the percentage of hexadecane in a mixture of hexadecane and 2-methyl naphthalene. Cetane is a saturated hydrocarbon ($C_{16}H_{34}$) having a short ignition delay and hence its cetane number is 100.

- Cetane number of methyl naphthalene is 0 since it has long ignition delay.

Cetane number can be improved by

- adding additives like ethyl nitrate, iso amyl nitrate, acetone peroxide, etc.

→ The order of cetane number is of the order:

[n-alkanes > naphthalenes > alkanes > branched alkanes > aromatics]

Biodiesel

04 Mar
Wed

- Biodiesel is a fuel which is obtained from raw materials which are biological in origin.
 - It is light yellow to dark yellow liquid with high B.P. and low vapour pressure.
 - It is immiscible in water and can be used by mixing with petro-diesel.
 - It can be used as a lubricant as its viscosity is good.
 - It is used in diesel engines.
 - It can be used as a domestic fuel.
 - It is non toxic.
 - It produces less emissions.
 - It produces less CO and CO₂.
 - Its contribution towards greenhouse effect is low.
 - Its cetane rating is high.
 - It is 98% biodegradable.
- * Sources of biodiesel:
- 1 - Groundnut oil.
 - 2 - Olive oil.

3 - canola oil.

4 - sunflower oil.

5 - Mustard oil.

6 - Refined/waste cooking oils.

7 - Animal fats, etc.

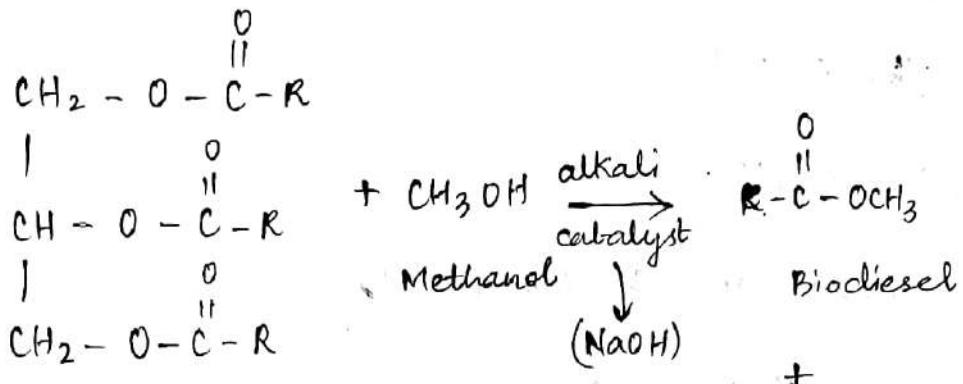
→ Raw materials used for making biodiesel are renewable.

→ Biodiesel is monoalkyl ester of long chain fatty acids.

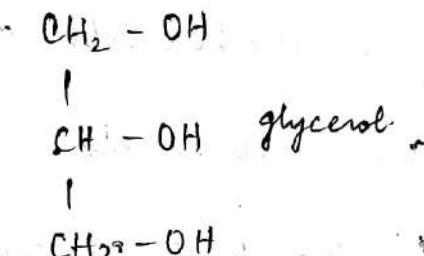
→ Biodiesel is obtained when organically derived oils are combined with alcohol in presence of catalyst and the process is called

trans-esterification.

* Transesterification: It is a process by which biodiesel is obtained. Organically derived oils (triglycerides) are combined with alcohol in presence of catalyst to produce biodiesel along with a byproduct called glycerol.



Triglycerides



transesterification is a reversible reaction.

therefore to stop the reverse reaction and to have more product formation, a stoichiometric ratio of 3:1 alcohol : oil (or)

6:1 alcohol: oil is used in the process.

The catalyst used can be acid or alkali or enzyme. An alkali catalyst NaOH is mostly used as reaction is fast with it and due to its ready availability and economical price.

Free fatty acids in the reaction are not desirable as they form soap during the reaction.

Soap formation obstructs separation of

biodiesel from glycerol. Therefore, anhydrous alcohol and oil are preferred in transesterification process. The byproduct glycerol obtained during this process can be used in making soap.

The energy audit of the biodiesel plant is

carried out by following a systematic procedure

and the results of which are discussed below:

1. Identification of plant & its working details

2. Biodiesel plant working conditions

3. Actual working capacity of plant

4. Actual working capacity of plant

5. Actual working capacity of plant

6. Actual working capacity of plant

7. Actual working capacity of plant

8. Actual working capacity of plant

9. Actual working capacity of plant

10. Actual working capacity of plant

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Composite Materials

- Materials obtained by combining dissimilar materials so that they work as single mechanical unit are called composite materials.
- Their properties are different from their constituents.
- Composite materials are made to improve the properties like:
 - Tensile Strength.
 - Corrosion resistance.
 - Reducing friction.
 - High temperature withstanding ability etc.

* Constituents of Composite Materials:

1. Matrix phase (or) matrix. - It is a main constituent of composite. It acts as binding material. It may be a metal; or

polymer or ceramic giving metal matrix composite (MMC)

(PMC) - polymer matrix composite or

(CMC) - ceramic matrix composite.

2- Fiber - It is a long thin filament used to increase the strength of a composite material.

Polymers, metals or ceramics are used.

3- Particulates - They are small pieces of hard material like concrete. They are used to increase surface hardness and reduce shrinkage and friction.

4- Whiskers - They are strong filaments of fibers of different length. They are used to increase strength of a composite material. Usually, graphite, sic are used.

* Advantages of Composite Materials:

- 1- They can withstand high temperatures.
- 2- They do not degrade at low temperatures.

3 - They possess corrosion resistance.

4 - Good tensile strength.

5 - They have high specific strength.

6 - Good conductivity that can be controlled.

* Types of Composites:

1 - Fiber-Reinforced Composites (FRC).

2 - Particulate Composites (PC).

3 - Layered Composites (LC).

i - FRC has mainly three constituents.

a - matrix.

b - filament / fiber.

c - whiskers.

Glass and metallic fibers are widely used.

They possess good stiffness, low density and good mechanical properties.

Main properties of FRC depends upon

nature of matrix and fiber used.

→ GFRC (Glass FRC) contains glass fibers with nylon or polyester as matrix. They possess good impact resistance, good chemical and corrosion resistance. They are used in making automobile parts and in transportation industries.

→ CFRP (carbon FRC) possesses C-fibers. They can withstand very high temperatures. They are used in making military components, some parts of commercial aircrafts and in golf sticks and bats. [drawback: high temp]

ii - PC are made by dispersing particulates of different sizes.

e.g. W-Carbide-Co composite

iii - LC : layers of different constituents of composites can be seen clearly. Widely used for many applications.

e.g. Plywood, steel vessel with Cu bottom; etc.