VTU Question paper solutions

First semester 1BCHES102 – ODD SEM 2025-26

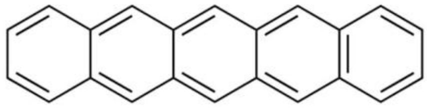
Subject: Applied Chemistry for Smart Systems (CSE)

Module 1: Functional Materials for Memory and Display Systems

Q1a. Explain p-type and n-type semiconductor materials used for organic memory devices.

p-type semiconductor materials that have an excess of positively charged holes, which can conduct electricity

Example: Pentacene is an organic semiconductor made of five linearly fused benzene rings (a polycyclic aromatic hydrocarbon).



Properties:

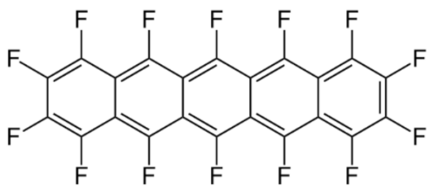
- **High charge carrier mobility**
- **Efficient hole transport** through its π-conjugated system.
- Supports **stable charge trapping** and helps in switching between ON and OFF states.
- Highly **sensitive to light** and has **high photoconductivity.**
- **Good crystallinity** and **smooth thin-film formation.**

Applications:

- **Organic Thin Film Transistors (OTFTs)**
- **Organic Field Effect Transistors (OFETs)**.

n-type semiconductor materials that have an excess of electrons in their conduction band.

Example: Perfluoropentacene is the fluoro derivative of pentacene where all hydrogen atoms are replaced with fluorine.



Properties:

- **High electron mobility**,
- **Strong electron-trapping ability**
- Shows **good chemical and thermal stability**
- Forms **well-ordered crystalline thin films**

Applications:

- **Resistive random-access memory (RRAM)** for stable ON/OFF switching
- **n-type active layer** in OFET-based memory devices

Q1b.Explain the synthesis of TiO_2-RAM nanomaterial by the sol–gel method and describe its properties and applications.

<u>TiO_2-RAM nanomaterial</u> refers to titanium dioxide nanostructures used as the active layer in resistive random-access memory (RRAM) devices. TiO_2 is widely used because of its stable resistive switching behavior.

<u>Synthesis of TiO_2 for ReRAM (Sol-Gel Method)</u>:

- A titanium precursor such as titanium isopropoxide or titanium butoxide is dissolved in alcohol.
- Controlled addition of water causes **hydrolysis**, forming a colloidal solution called a ***sol***.

$$\text{Ti-OR} + H_2O \rightarrow \text{Ti-OH} + \text{R-OH}$$

$$\text{Ti-OH} + \text{RO-Ti} \rightarrow \textbf{Ti-O-Ti} + \text{R-OH}$$

- Further condensation reactions convert the **sol** into a three-dimensional ***gel*** network.
- The gel is dried and calcined (300–500°C) to obtain crystalline **anatase TiO_2 nanomaterial**
- The final material can be deposited as a thin film between metal electrodes for RRAM devices.

<u>Properties</u>

- **Non-volatility** → Retains data without power.
- **High switching speed** (ns–μs).
- **Bipolar/Unipolar resistive switching behavior**.
- **Low power consumption** compared to Flash memory.
- **Good endurance and retention**

<u>Applications</u>

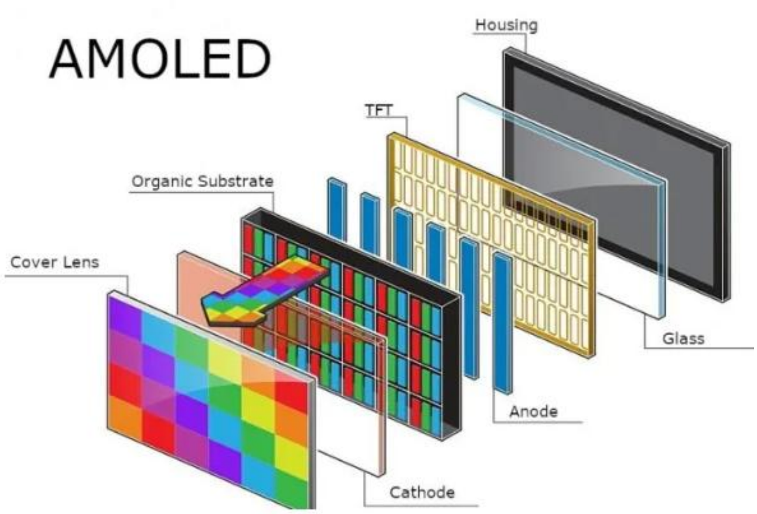
- **Non-volatile memory storage**
- **Neuromorphic computing**
- **Reconfigurable logic devices**.
- **Flexible and wearable electronics**
- **High-density storage devices**

Q1c. Describe the construction and working principle, and its applications of Active-Matrix Organic Light Emitting Diodes (AMOLEDs)

AMOLED (Active-Matrix Organic Light Emitting Diode) is a display technology where each pixel is made of organic materials that emit light. It uses a thin-film transistor (TFT) matrix to actively control each pixel for better brightness, contrast, and efficiency.

<u>Construction of AMOLED</u>

- **Substrate**: Glass or flexible plastic that supports the entire structure.
- **Thin Film Transistor Backplane**: Active matrix circuit that controls each pixel's switching and brightness.
- **Transparent Anode:** Injects holes into the organic layers.
- **Hole Transport Layer**: Helps holes move efficiently toward the emissive layer.
- **RGB Emissive Organic Layer**: Produces red, green, or blue light when electrons and holes recombine.
- **Electron Transport Layer**: Helps electrons move toward the emissive layer.
- **Cathode (Metal Electrode)**: Injects electrons into the organic layers.
- **Encapsulation Layer**: Protects OLED materials from moisture and oxygen.



Working Principle

- Each pixel has its own **TFT and storage capacitor** that control the current flowing through the OLED.
- When a voltage signal is applied, the TFT switches ON and allows current to flow to the OLED pixel.
- The **anode injects holes** and the **cathode injects electrons** into the organic layers.
- Electrons and holes move toward the emissive layer and **recombine to emit light**.
- The **brightness of each pixel** depends on the amount of current controlled by the TFT.
- Since each pixel emits its own light, **no backlight is required**.
- The **active matrix** ensures fast response, low power consumption, and stable images.

Applications in Modern Display Technology

- Used in **smartphones and tablets**
- **smartwatches and wearable devices**
- **AMOLED TVs** with thin and lightweight panels
- **foldable and flexible displays**

- **automotive displays and AR/VR devices**

Q2a.Discuss the construction, working and advantages of pentacene semiconductor chip

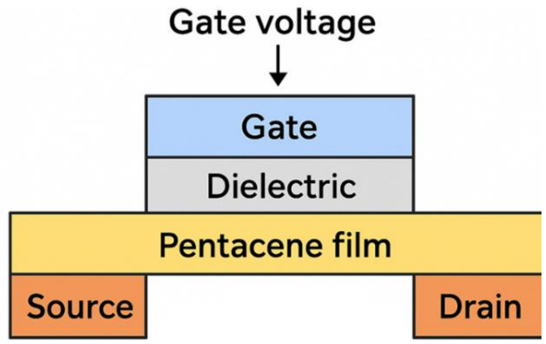
A **pentacene semiconductor chip** is an **organic electronic device** in which **pentacene** is used as the **active semiconducting layer,** which is deposited as a thin film between electrodes.

When a voltage is applied, holes move through the pentacene layer, allowing the device to switch electrical signals.

Construction

Pentacene-based chips are commonly used in organic field-effect transistors (OFETs). The main construction components are:

Substrate/Gate: Si (serves as gate).
Gate dielectric: 200–300 nm SiO_2
Semiconductor: Pentacene 30–50 nm
Contacts: Au (30–50 nm) source/drain
Encapsulation: Parylene-C polymer



Working

- When voltage is applied to the gate electrode, an electric field is formed across the dielectric.
- This field induces charge carriers (holes) in the pentacene layer, forming a conductive channel between source and drain electrodes.
- The amount of current that flows depends on the gate voltage
- Because of its π-conjugated structure, pentacene allows efficient charge delocalization, leading to relatively high mobility for an organic material.

Advantages

- Mechanical Flexibility
- Low-Temperature and Low-Cost Fabrication
- Chemical Tunability
- High Hole Mobility
- Lightweight

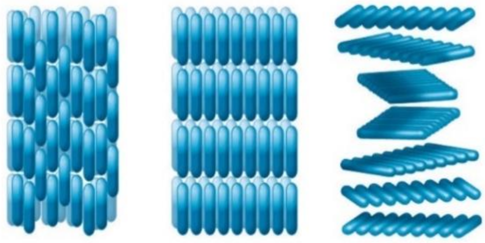
Q2b. What are liquid crystals (LCs)? Discuss their classifications

<u>Liquid crystals (LCs)</u>: An ordered fluid mesophase of an organic long-chain molecules possessing both **solid-like molecular order** and **liquid-like character** is known as a liquid Crystal.

<u>Classification</u>

(a) Thermotropic liquid crystals: When long-chain organic solids are heated, they undergo sharp phase transitions at a particular temperature yielding liquid crystals.

Thermotropic liquid crystals are three types:



<u>Nematic</u>: The molecules move either sideways or up and down. In this case, the molecules are readily aligned in the same direction in the presence of ***electric and magnetic fields***. The alignment of molecules is ***temperature sensitive***.

Example: p-azoxyphenetole,

<u>Smectic</u>: The molecules in smectic crystals are oriented parallel to each other as in the nematic phase but in layers. These layers can pass on each other because the force between the layers is weak.

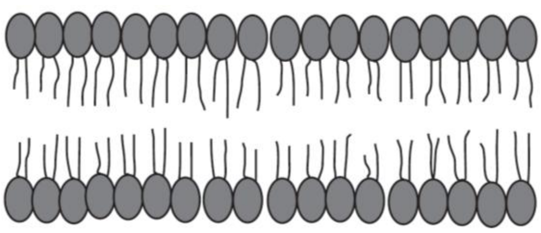
Example: smectic–A

<u>Cholesteric</u>: The molecules in successive layers are slightly twisted or rotated with respect to the layers above and below to form a continuous helical or spiral pattern.

Example: Cholesteryl benzoate

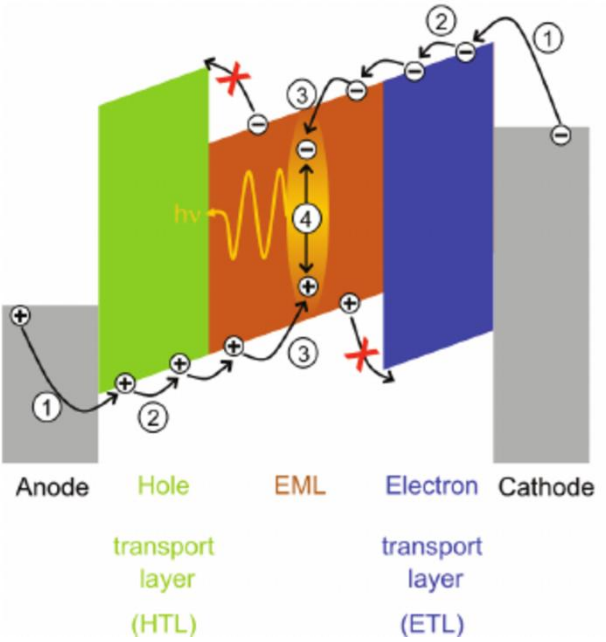
(b) <u>Lyotropic liquid crystals:</u> The orientational behaviour of lyotropic crystals is a function of concentration and solvent. These molecules are amphiphilic in nature–they have both hydrophilic and hydrophobic ends in their molecules. At low concentrations, these molecules are randomly oriented but as the concentration increases, the molecules start arranging themselves.

Example: Cell membranes



Q2c. Explain the construction and working principle of Organic Light Emitting Diodes (OLEDs) and discuss its applications in electronic displays

Organic Light Emitting Diode (OLED) is a type of display technology that utilizes organic materials to emit light when an electric current is applied.



Construction

- **Glass or plastic substrate:** base of OLED
- **Anode**: transparent material like indium tin oxide (ITO).
- **Hole Transport Layer (HTL)**
- **Emissive Layer**: where light is produced.
- **Electron Transport Layer (ETL)**
- **Metal Cathode:** aluminium.

Working principle

- When a voltage is applied across the OLED device, the anode becomes positive and the cathode becomes negative. This causes **holes** to be injected from the anode and **electrons** from the cathode.
- The **holes travel through the Hole Transport Layer (HTL)**, while electrons move through the **Electron Transport Layer (ETL)**.
- When an electron and a hole recombine in the **Emissive layer** (EML), their energy is released in the form of **a photon (light)**. The color of light depends on the type of **organic material used** (red, green, or blue).
- Since the **anode** is transparent, the light generated inside the OLED passes outward through it, producing a **visible display**.

Applications

- **Smartphones, tablets, and smartwatches**
- **OLED televisions**
- **Flexible, foldable, and rollable displays**
- **Automotive dashboards**

Module 2: Quantum Materials and Polymers

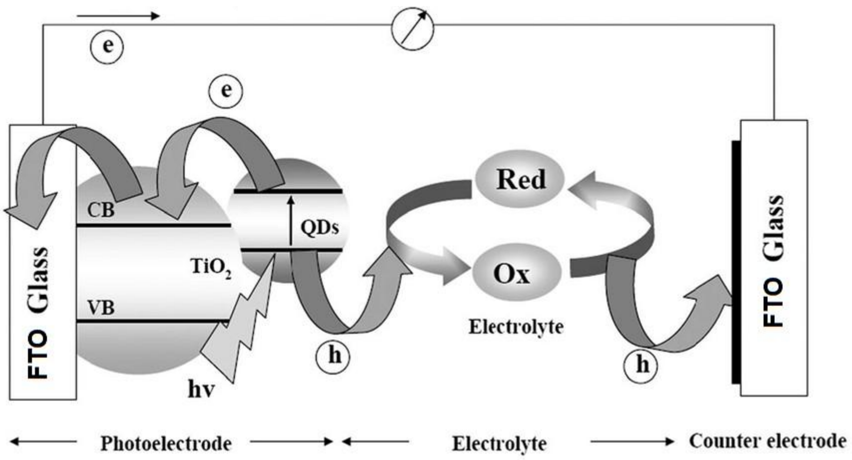
Q3a. Discuss construction, working principle and applications of quantum dot sensitized solar cells (QDSSCs).

QDSCs

A quantum dot solar cell (QDSC) is a type of solar cell that utilizes quantum dots as a light-absorbing material to convert sunlight into electricity.

Construction

- ***Transparent conducting electrode***: FTO glass (Fluorine-doped Tin Oxide)
- ***Transparent Conductive Oxide Layer***: TiO_2 film
- ***Quantum dots layer***: Light-absorbing semiconductor materials (CdSe or CdS)
- ***Electrolyte***: Polysulphide is used as a redox electrolyte.
- ***Counter Electrode***: used to complete the circuit and helps to generate electricity.



Working

a) Upon absorption of a photon, a quantum dot is excited from the ground state (QDS) to a higher energy state (QDS*)

Excitation process: QDs + hv → QDs*

b) The absorption process results in the creation of electron-hole pair in the form of the ***exciton***. Dissociation of the exciton occurs if the thermal energy exceeds its binding energy

Exciton dissociation: QDs* → e-* + h+ (free energy)

c) The excited electron is then injected in the conduction band of the wide bandgap semiconductor nanostructured TiO_2 thin film. This process will cause the oxidation of the photosensitizer

Injection process: QDs* + TiO_2 → TiO_2e^{-*} + QDs^+

d) The injected electron is transported between the TiO_2 nanoparticles, and then gets extracted to a load where the work done is delivered as electrical energy.

Energy generation: $TiO_2e^{-*} + C.E \rightarrow TiO_2 + e^*$ (CE)

QDSCs applications

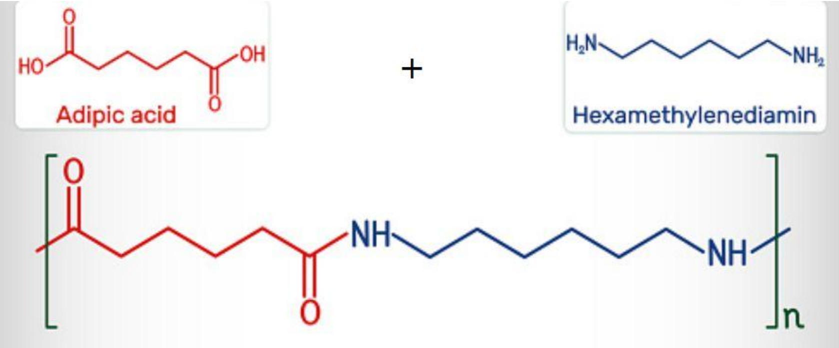
- It is used as light-emitting Diodes
- It is used as a photoconductor and photodetector
- It is used as a photovoltaic
- It is used in biomedicine
- It is used in catalysis

Q3b. What is polymer? Describe its synthesis, properties, and advantages in 3D printing applications.

Polymers: Polymers are high molecular weight organic compounds in which a large number of simple units regularly repeat themselves. The simple units are called monomers.

Nylon-6,6: Nylon-6,6 is an important engineering polymer known for its high strength, durability and thermal stability. It is a ***synthetic polyamide*** made from two monomers, each containing six carbon atoms.

Synthesis: Nylon-6,6 is prepared by condensation polymerization of hexamethylene diamine with adipic acid at high temperature and pressure. These monomers react to form a long polyamide chain with the repeating unit.



Properties:

- High strength due to strong hydrogen bonding between chains.
- Good thermal stability and can be stable up to 260°C.
- Excellent abrasion and wear resistance.
- Good chemical resistance to oils, solvents and many reagents.

Advantages in 3D Printing Applications

- Produces strong and durable printed parts suitable for functional use.
- Good layer adhesion, which reduces the chances of cracking.
- High flexibility, preventing brittleness during and after printing.
- Can handle mechanical stress and repeated loading.
- Smooth surface finish with minimal post-processing.

Q3c. A polymer sample containing 50, 100 and 150 molecules having molar mass 1000, 2000 and 3000, respectively. Calculate the number and weight average molecular weights of the polymer.

Given data:

Number of molecules (Ni)	Molar mass (Mi in g/mol)
N1= 50	M1 = 1000
N2=100	M2 = 2000
N3=150	M3 = 3000

Number Average Molecular Weight (Mn):

$$\boldsymbol{M_n = \frac{\sum N_i M_i}{\sum N_i}}$$

ΣNiMi$= (50 \times 1000) + (100 \times 2000) + (150 \times 3000) = 50000 + 200000 + 450000$
$= 700000$

ΣNi$= 50 + 100 + 150 = 300$

$$M_n = \frac{700000}{300};\ \boldsymbol{M_n = 2333\ g/mol}$$

Weight Average Molecular Weight (Mw)

$$\boldsymbol{M_w = \frac{\sum N_i M_i^2}{\sum N_i M_i}}$$

ΣNiMi²:$= (50 \times 1000^2) + (100 \times 2000^2) + (150 \times 3000^2)$
$= (50 \times 1000000) + (100 \times 4000000) + (150 \times 9000000)$
$= 50000000 + 400000000 + 1350000000\ = 1800000000$

$\sum N_i M_i = 700000$

$$M_w = \frac{1800000000}{700000}$$
$$\boldsymbol{M_w = 2571.43\ g/mol}$$

Q4a. Describe the following structure property relationship of the polymer.
a) Crystallinity b) Strength c) Chemical resistivity.

Structure–Property Relationship in Polymers

The properties of a polymer depend on how its chains are arranged and how strongly they interact. Small changes in structure can strongly affect physical and mechanical properties.

Crystallinity: Polymers with well-packed and ordered chains show higher crystallinity. When chains are arranged tightly, the material becomes harder, stronger and less flexible. Crystallinity also increases density and melting point. In contrast, amorphous polymers are more flexible and transparent.

Strength: Strength depends on chain length, chain arrangement and intermolecular forces. Long chains with strong interactions like hydrogen bonding resist breaking under stress. Cross-linking also improves strength by tying chains together, making the polymer tougher.

Chemical Resistivity: This depends on the polymer's structure and the presence of polar or reactive groups. Non-polar, highly hydrophobic polymers resist many chemicals because solvents cannot easily penetrate or react with their chains. Cross-linked and crystalline polymers also show better resistance.

Q4b. Explain the wet chemical synthesis of Cd-Se quantum dots and mention its application.

Synthesis of Cd-Se Quantum dots by wet chemical method

The **wet chemical (colloidal synthesis) method** is the most common, as it is simple and cost-effective.

Precursors:

- **Cadmium source**: Cadmium salts ($CdCl_2$, $Cd(Ac)_2$).
- **Selenium source**: Sodium selenide (Na_2Se) dissolved in trioctylphosphine (TOP).

Reaction Medium: Organic solvents like **trioctylphosphine oxide (TOPO)** or oleic acid act as **capping agents to control particle size** and prevent aggregation.

Nucleation and Growth: Cd precursor and Se precursor are injected into a hot surfactant solution. At high temperature (~200–300°C) **nucleation occurs** and formation of tiny CdSe **nanocrystals**.

Purification: The nanocrystals are separated by precipitation (adding ethanol/acetone) and redispersed in solvents like toluene or hexane.

Applications of CdSe QDs

1. **Optoelectronic Devices**: **QLED displays, LEDs, and lasers**
2. **Solar Cells**: CdSe QDs enhance photovoltaic performance.
3. **Biological Imaging**: **cell and tissue imaging**
4. **Sensors**: CdSe QDs can detect chemicals, ions, or biomolecules

Photocatalysis: Effective in **hydrogen generation**

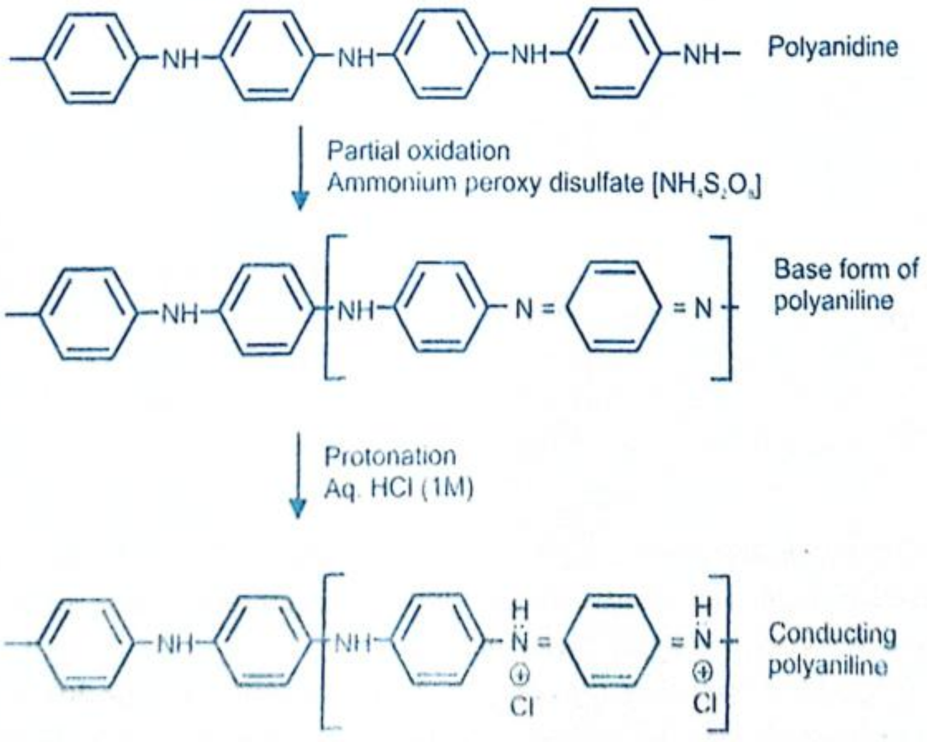
Q4c. Polymers are generally known for their insulating nature. Applying the knowledge of the conduction mechanism, highlight and explain the conduction mechanism in Polyaniline polymer. Mention its engineering applications.

Conducting polymer: Conducting polymers are a special class of organic polymers that can conduct electricity, unlike most conventional polymers which act as insulators.

Conduction mechanism: Protonic Acid Doping

In this technique, current-carrying charged species (−ve / +ve) are created by the protonation of imine nitrogen.

- Polyaniline is partially oxidized first, using a suitable oxidizing agent, into a base form of aniline which contains alternating reduced and oxidized forms of the aniline polymer backbone.
- This base form of aniline, when treated with aqueous HCl (1M), undergoes protonation of the imine nitrogen atom.
- Protonation creates current carrying charged sites (+ve) in the polymer backbone.
- These charges are compensated by the anions (Cl^-) of the doping agent, giving the corresponding salt.
- Protonic acid doping of polyaniline results in an increase of conductivity by approximately 9–10 orders of magnitude.

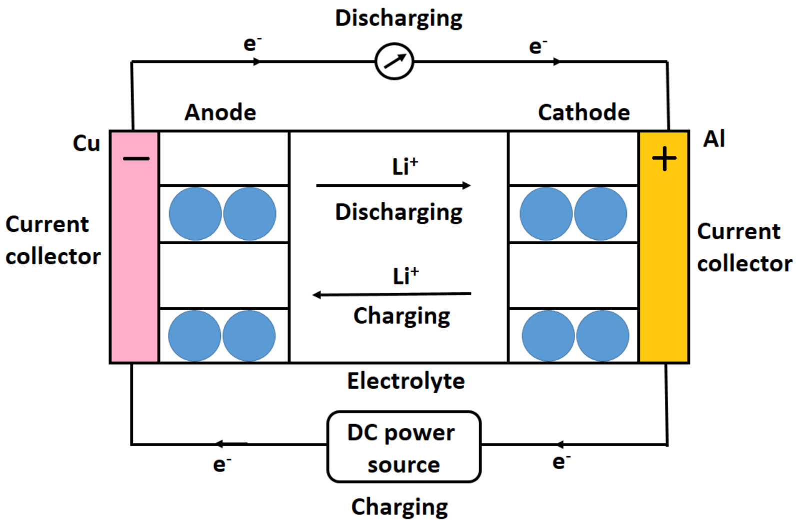


Module 3: Sustainable Energy Systems

Q5a.Describe the construction and working of Lithium-ion Battery

Construction

Anode (negative electrode): Lithium intercalated graphite layer (Li_xC)
Cathode (positive electrode): Lithium metal oxide, e.g. $LiCoO_2$
Electrolyte: Lithium salt ($LiPF_6$) dissolved in ethylene carbonate + dimethyl carbonate
Separator: Porous polyolefin polymer film
Current Collectors: Copper foil for the anode, aluminium foil for the cathode.



Working Principle

The battery operates based on the **reversible intercalation and de-intercalation of lithium ions** between the anode and cathode.

During Discharging **(battery in use)**

- Li^+ ions move **from anode → through electrolyte → to cathode**.
- Electrons flow externally from **anode → cathode**, powering the device.
- The process is reversed compared to charging.

Anode: $$\mathrm{LiC_6} \rightarrow C_6 + Li^+ + e^-$$

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

DuringCharging
(external power applied)

- Li^+ ions move **from cathode → through electrolyte → into anode (graphite layers)**.
- Electrons move externally from **cathode → anode** to maintain charge balance.

- Anode stores Li^+ ions as **$Li\text{-}C_6$ (lithiated graphite)**.

$$\text{Cathode (LiCoO}_2) \rightarrow \text{Li}_{1-x}CoO_2 + xLi^+ + xe^-$$

$$\text{Anode (C)} + xLi^+ + xe^- \rightarrow Li_xC_6$$

Q5b.Explain the production of green hydrogen using TiO2: photocatalytic water splitting method.

Photocatalytic water splitting is a process to produce green hydrogen using solar energy to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). ***Titanium dioxide*** (TiO_2) is a widely studied ***semiconductor photocatalyst*** due to its stability, non-toxicity, and low cost.

Process Steps:

- **Light Absorption**: When TiO_2 is exposed to ultraviolet (UV) light, it absorbs photons with energy equal to or greater than its bandgap (~3.2 eV).
- **Excitation**: This excites electrons (e^-) from the valence band to the conduction band, leaving behind holes (h^+) in the valence band.
- **Charge Separation**: Electron-hole pairs are generated; electrons move to the conduction band, holes remain in the valence band. These charges migrate to the surface of the TiO_2 particles.

Redox Reactions on Catalyst Surface:

- **Reduction Reaction (at conduction band):**
  Electrons reduce protons (H^+) from water to produce hydrogen gas (H_2):

$$2H^+ + 2e^- \rightarrow H_2$$

- **Oxidation Reaction (at valence band):**
  Holes oxidize water molecules to produce oxygen gas (O_2):

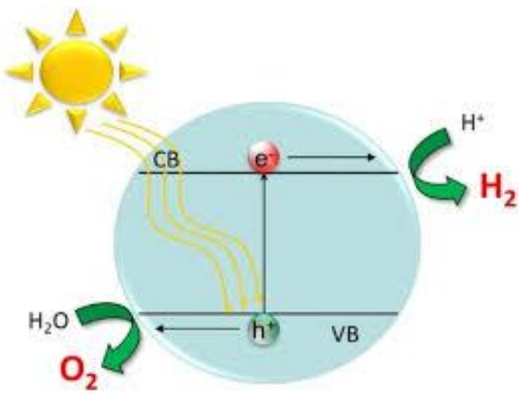
$$2H_2O + 4h^+ \rightarrow O_2 + 4H^+$$

- **Overall Reaction:**

$$2H_2O \xrightarrow{\text{TiO}_2\text{+light}} 2H_2 + O_2$$

Advantages

- Produces **clean hydrogen** without greenhouse gas emissions.
- Uses **abundant solar energy** and water, making it sustainable and eco-friendly.
- Provides **direct conversion of sunlight to hydrogen fuel** with high purity.



Q5c. The emf of a cell Ag(s) /AgNO;(0.02M) / AgNO;(XM) / Ag(s) is found to be 0.084V at 298 K. Find the value of X and write the cell reactions.

Given:

Cell Representation: Ag(s) | $AgNO_3$ (0.02 M) || $AgNO_3$ (X M) | Ag(s)

E_{Cell} = 0.084 V
Temperature, T = 298 K
For $Ag^+ + e^- \rightarrow Ag(s)$, n = 1

Cell reactions

Anode (oxidation, lower concentration side): $Ag(s) \rightarrow Ag^+(0.02\ M) + e^-$

Cathode (reduction, higher concentration side): $Ag^+(0.528\ M) + e^- \rightarrow Ag(s)$

For concentration cell: $E = \frac{0.0591}{n} \log \frac{C_2}{C_1}$

Where: C_2 = higher concentration and C_1 = lower concentration

$$0.084 = \frac{0.0591}{1} \log \frac{X}{0.02}$$

$$\log \frac{X}{0.02} = \frac{0.084}{0.0591} = 1.421$$

$$\frac{X}{0.02} = 10^{1.421} = 26.38$$
$$X = 26.38 \times 0.02$$
$$\boldsymbol{X = 0.528\ \mathrm{M}}$$

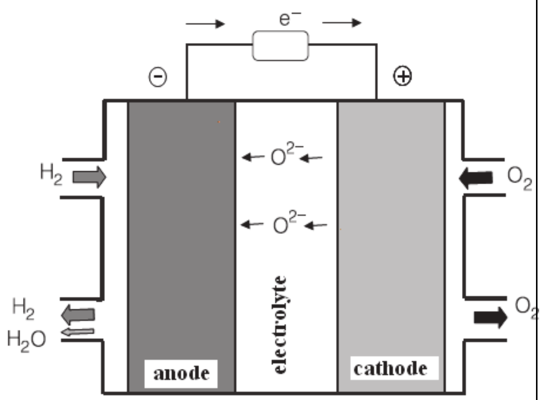
Q6a. A fuel cell is considered as an efficient energy conversion devce to convert fuel energy into electricity operating at wide temperature range. Apply the concept of energy conversion and outline the characteristics, construction and working of solid oxide fuel cell.

A **Solid Oxide Fuel Cell (SOFC)** is constructed as a layered structure, where each component plays a specific role in the electrochemical conversion process.

Construction

A Solid Oxide Fuel Cell is built in a layered structure:

Electrolyte: Porous solid ceramic oxide (**yttria-stabilized zirconia)**
Anode (Negative Electrode): **Ni-YSZ cermet** (nickel–zirconia composite)-
Cathode (Positive Electrode): Strontium-doped Lanthanum Manganite
(LSM) – Interconnects: Metallic/ceramic materials
Fuel Channel: Supplies fuel gas (hydrogen)
Air Channel: Supplies oxidant (oxygen from air)



Working Principle of SOFC

The SOFC works on the principle of ***electrochemical conversion of chemical energy (fuel + oxidant) into electrical energy*** without combustion.

At the Cathode (Air side): Oxygen molecules receive electrons from the external circuit and form oxide ions (O^{2-}):

$$O_2 + 4e^- \rightarrow 2O^{2-}$$

The oxygen ions (O^{2-}) migrate through the solid electrolyte towards the anode.
At the Anode (Fuel side): Fuel (hydrogen) reacts with oxygen ions to form water and release electrons.

$$H_2 + O^{2-} \rightarrow H_2O + 2e^-$$

Electron Flow: The released electrons from the anode travel back to the cathode through the external circuit, producing **electric current.**

Overall Reaction: $H_2 + ½O_2 \rightarrow H_2O + \text{electricity} + \text{heat}$

Q6b. Explain the construction and working of Sodium ion Battery and mention its applications

Construction

- **Anode (Negative Electrode):** Sodium Intercalated Hard carbon
- **Cathode (Positive Electrode):** layered transition metal oxides ($NaMO_2$ M= Fe, Mn, Cu, Mo)
- **Electrolyte:** Sodium salts (e.g., $NaPF_6$) dissolved in organic solvents (carbonate-based).
- **Separator:** Microporous polymer membrane.
- **Current Collectors:** Aluminum foils to conduct electrons.

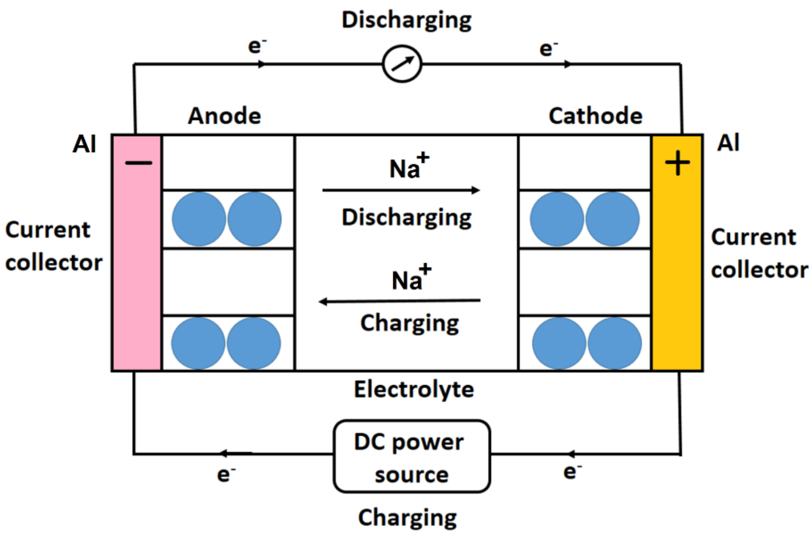
Working Principle

Discharging (Battery in use): Sodium ions (Na^+) move from the **anode to the cathode** through the electrolyte. Electrons flow through the external circuit, providing electrical energy.

- **Anode :** $NaC \rightarrow C + Na^+ + e^-$
- **Cathode** $Na_{1-x}MO_2 + xNa^+ + xe^- \rightarrow NaMO_2$

Charging process (external power applied): An external power source drives sodium ions from the cathode back to the anode. Electrons also flow back into the anode.

- **Cathode** $NaMO_2 \rightarrow Na_{1-x}MO_2 + xNa^+ + xe^-$
- **Anode** $C + Na^+ + e^- \rightarrow NaC$



EV Applications of sodium-ion battery

- Serve as an **alternative power source** for EVs where low cost is important, since sodium is more abundant and cheaper than lithium.
- Provide **good safety and thermal stability**, reducing risks of overheating in vehicles.
- Suitable for **short-range and low-speed EVs** such as e-rickshaws, scooters, and small cars.
- Offer **sustainability and resource availability**, making them promising for large-scale EV deployment in the future.

Q6c. What is a battery? Outline the classification of battery with suitable examples.

Battery: A battery is a device that converts chemical energy directly into electrical energy via an electrochemical oxidation and reduction reaction.

Classification of Batteries

Batteries can be classified based on their **rechargeability**.

(a) Primary Batteries (Non-rechargeable)

- Designed for **single use**; cannot be recharged.
- Chemical reaction is **irreversible**.
- Examples:
    - Dry cell (Leclanché cell, Zn–C)
    - Alkaline battery (Zn–MnO_2)

Applications: Flashlights, remote controls, toys, clocks

(b) Secondary Batteries (Rechargeable)

- Can be **recharged multiple times** with external current.
- Reactions are **reversible**.
- Examples:
    - Nickel–cadmium (Ni–Cd)
    - Lithium-ion (Li-ion) batteries

Applications: Cars, laptops, smartphones, UPS systems

(c) Reserve battery

- A battery that remains **inactive** until it is needed.
- The chemicals that produce electricity are **kept separate** to prevent self-discharge.
- Activated by **adding electrolyte, breaking a seal, or applying pressure/heat**.
- Provides **long storage life** and instant power when triggered.

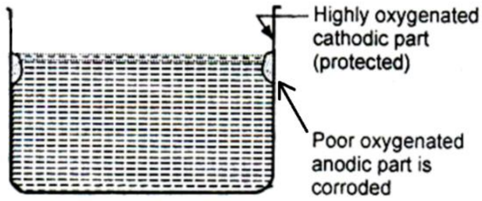
Module 4: Sensors and Corrosion Science

Q7a. Explain the mechanism of Pitting corrosion and Waterline corrosion with suitable examples.

Water line corrosion

- ❖ Waterline corrosion occurs on metal structures at the waterline, where the surface is exposed to both air and water.

- ❖ The portion above the waterline is exposed to high oxygen concentration, acts as a cathodic area, and remains unaffected.
- ❖ While the portion below the waterline has a *low* oxygen *concentration* acts as an anodic area that undergoes corrosion.
- ❖ A *distinct brown line* is formed just below the *water line* due to the deposition of rust.



Cell Reaction:

At anode: $Fe \rightarrow Fe^{2+} + 2e^-$

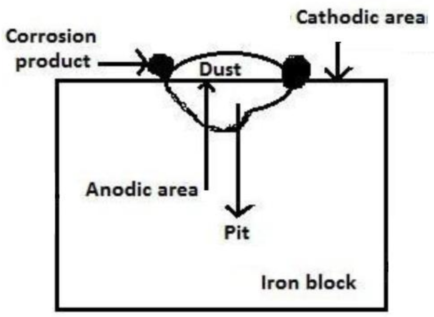
At cathode: $O_2 + 2\ H_2O + 4e^- \rightarrow 4\ OH^-$

$2\ Fe^{2+} + 4\ OH^- \rightarrow 2\ Fe(OH)_2$

$4\ Fe(OH)_2 + O_2 + 2H_2O \rightarrow 2\ [Fe_2O_3.3H_2O]$

Pitting line corrosion

- ❖ Pitting line corrosion arises when a small portion of the metallic surface is covered by dust or oil drops.
- ❖ The metal portion below the dust which is exposed to a *low* oxygen *concentration* acts as an anodic area that undergoes corrosion and a pit is formed.
- ❖ The whole remaining part of the metal which is exposed to a high oxygen concentration acts as a cathodic area and remains unaffected.



Cell Reaction:

Similar cell reactions like waterline corrosion

Q7b. Explain the principle, construction and application of Electrochemical sensors in the detection ofNOx and Sox.

Electrochemical gas sensors detect toxic gases like sulfur oxides (SOx) and nitrogen oxides (NOx) by measuring the electrical current generated from the **redox (oxidation-reduction) reactions** of these gases at an electrode surface.

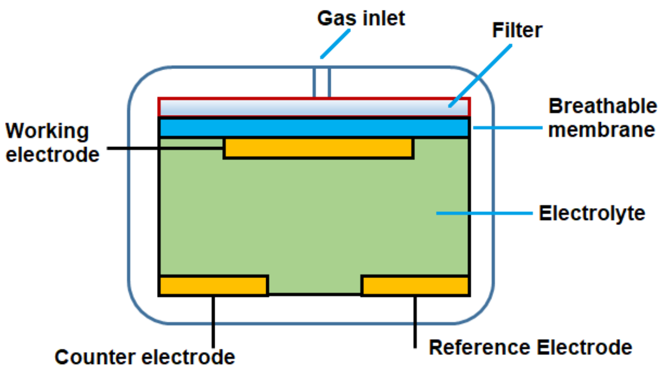
Construction

- ***Working electrode*** (sensing electrode): **Gold**
- ***Counter electrode***: **Platinum** to complete the circuit.
- ***Reference electrode***: **Ag/AgCl** to maintain a constant potential

- ***Electrolyte***: ionically conducting materials (**3-7M H_2SO_4**)
- ***Membrane***: A gas-permeable membrane is used to control the gas flow reaching the electrode surface.
- ***Filter:*** to filter out the unwanted gas

<u>Working principle</u>

- **Gas Diffusion:** The target gas (SOx or NOx) diffuses through a porous membrane or diffusion barrier to the sensor's **working electrode**.



- **Electrochemical Reaction at Working Electrode:** The gas undergoes a **redox reaction** (oxidation or reduction) on the electrode surface.
  Working electrode (Anode): $SO_2 + H_2O \rightarrow SO_3 + 2\,H^+ + 2\,e^-$
  Counter electrode (Cathode): $(1/2)\,O_2 + 2\,H^+ + 2\,e^- \rightarrow H_2O$

  Working electrode (Anode): $NO + H_2O \rightarrow NO_2 + 2\,H^+ + 2\,e^-$
  Counter electrode (Cathode): $(1/2)\,O_2 + 2\,H^+ + 2\,e^- \rightarrow H_2O$
- **Electron Transfer and Current Generation:** The redox reaction causes **electron transfer** at the working electrode, generating a measurable **current** proportional to the gas concentration.

- **Signal Output:** The current produced is directly proportional to the concentration of SOx or NOx, allowing quantitative detection.

Q7c. What is CPR? Ath ick sheet of area 93 inch 2 is exposed to air near the ocean. After 6 months it was found to experience a weight loss of 360 g due to corrosion, if the density of the steel is 7.9 g/cm. Calculate the corrosion penetration rate in mpy and mmpy (Given K=534 in mpy and 87.6 mm/y).

CPR (Corrosion Penetration Rate) is the rate at which corrosion penetrates into a material. It indicates the thickness of metal lost per unit time due to corrosion. It is usually expressed in: **mpy** (mils per year, where 1 mil = 0.001 inch) and **mm/year** (millimeters per year)

Given data:

Area, A = 93 $inch^2$
Weight loss, W = 360 g = 360 x 10^3 mg
Density, D = 7.9 g/cm^3
Time, T = 6 months = 6 x 30 x 24 hrs = 4320 hrs

Constants:
K = 534 (for mpy)
K = 87.6 (for mm/year)

In mpy: $CPR(mpy) = \frac{K \times W}{D \times A \times T}$

$$CPR = \frac{534 \times 360 \times 1000}{7.9 \times 93 \times 4320}$$

$$\boldsymbol{CPR = 60.56} \textbf{ mpy}$$

In mm/year: $CPR(mm/year) = \frac{87.6 \times W}{D \times A \times T}$

$$CPR = \frac{87.6 \times 360 \times 1000}{7.9 \times 93 \times 6.45 \times 4320}$$

$$\boldsymbol{CPR = 1.52} \textbf{ mm/year}$$

Q8a. What is corrosion? Explain electrochemical theory of corrosion by taking iron as an example.

The electrochemical theory of corrosion explains corrosion as a **redox reaction** occurring in the presence of moisture and oxygen. It involves the formation of anodic and cathodic regions on the metal surface.

Mechanism of Iron Corrosion:

Formation of Anodic and Cathodic Sites:

- Due to surface impurities, iron (Fe) develops anodic and cathodic regions in the presence of an electrolyte (e.g., water with dissolved oxygen).

Anodic Reaction (Oxidation):

- At the anode, iron loses electrons and forms iron ions: $Fe \rightarrow Fe^{2+} + 2e^-$
- This reaction leads to the dissolution of iron.

Cathodic Reaction (Reduction):

- The electrons lost by iron are accepted by oxygen and water at the cathodic region: $O_2 + 4H^+ + 4e^- \rightarrow$ **$2H_2O$**
- In neutral or slightly basic conditions, the reaction is:
  $O_2 + 2H_2O + 4e^- \rightarrow$ **$4OH^-$**

Formation of Rust (Hydrated Iron Oxide):

- The Fe^{2+} ions react with OH^- to form iron(II) hydroxide:
  $2Fe^{2+} + 4OH^- \rightarrow$ **$2Fe(OH)_2$**

- Further oxidation of $Fe(OH)_2$ in air leads to rust [hydrated iron(III) oxide]:
  4 $Fe(OH)_2 + O_2 + 2H_2O \rightarrow 2$ [$\mathbf{Fe_2O_3.3H_2O}$] ***Yellow rust***
- In the presence of oxygen, ferrous hydroxide is converted into ***magnetic oxide***, known as black rust.
  3 $Fe(OH)_2 + \frac{1}{2} O_2 \rightarrow$ $\mathbf{Fe_3O_4.3H_2O}$ ***Black rust***

Q8b. Explain the application of Conductometric sensors in the estimation of acid mixture.

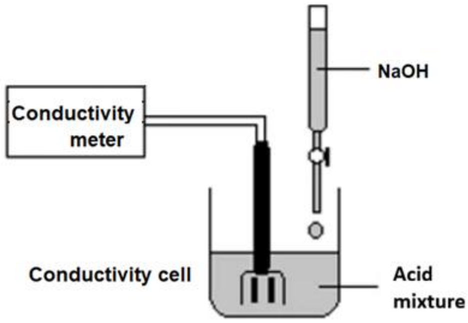
Conductometric sensors are widely used to determine the composition and concentration of acid mixtures based on their electrical conductivity.

Estimation of Acid Mixture (Strong Acid HCl + Weak Acid CH_3COOH) using a conductometric sensor

Conductometry measures the electrical conductance of a solution, which depends on the number and mobility of ions. When an acid mixture is titrated with a standard base such as sodium hydroxide (NaOH), the hydrogen ions (H^+) from the acid react with hydroxide ions (OH^-) from the base to form water. This neutralization changes the number of ions in the solution, resulting in a change in conductivity. By monitoring this change, the concentration of acids can be determined.

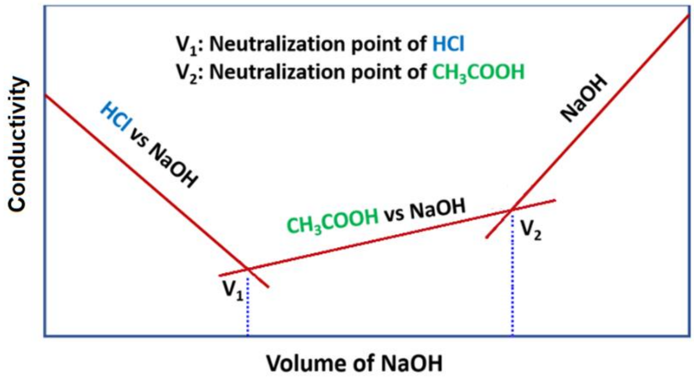
Instrumentation:

- Conductivity cell with two platinum electrodes
- Conductivity meter
- Burette with standard NaOH solution (titrant)
- Beaker containing acid mixture
- Magnetic stirrer



Step-wise process:

- **Initial stage:** The conductivity is high because strong acid (HCl) is fully ionized, producing a large number of H^+ ions, which have very high mobility.
- **Neutralization of strong acid:** When NaOH is added, H^+ ions react with OH^- ions to form water. These highly mobile H^+ ions are replaced by less mobile Na^+ ions, so conductivity decreases.
- **Neutralization of weak acid:** After complete neutralization of HCl, NaOH starts reacting with acetic acid. Since acetic acid is weakly ionized, its neutralization produces acetate ions (CH_3COO^-), increasing the number of ions. Therefore, conductivity begins to increase gradually.
- **After complete neutralization:** Further addition of NaOH increases conductivity sharply due to the presence of excess OH^- ions, which have high mobility.



Q8c. Define the terms a) Transducer b) Actuators c) Sensors.

<u>Transducer</u>

- A transducer is a device that **converts one form of energy into another**.
- **Example**: A microphone converts sound waves (mechanical energy) into electrical signals.

<u>Sensors</u>

- A sensor is a type of device (***transducer***) that **detects, measures, or senses physical quantities** (such as temperature, pressure, light, humidity, motion, or chemical composition) and converts them into electrical signals.
- **Examples**: temperature sensors and pressure sensors, etc.

<u>Actuator</u>

- An actuator is a device that ***converts electrical signals into physical action*** or movement.
- **Examples** include motors, solenoids and valves.

Module 5: Green Materials and E-Waste Management

Q9a. Describe the role of artificial intelligence in e-waste management

<u>Role of AI in e-waste management</u>

Artificial intelligence plays a crucial role in enhancing the management of electronic waste, from collection to recycling.

- **Smart collection and sorting**: AI uses cameras and sensors to identify e-waste such as mobile phones, circuit boards, and batteries. Machine learning enables fast, accurate sorting, reducing human error and improving recycling efficiency.

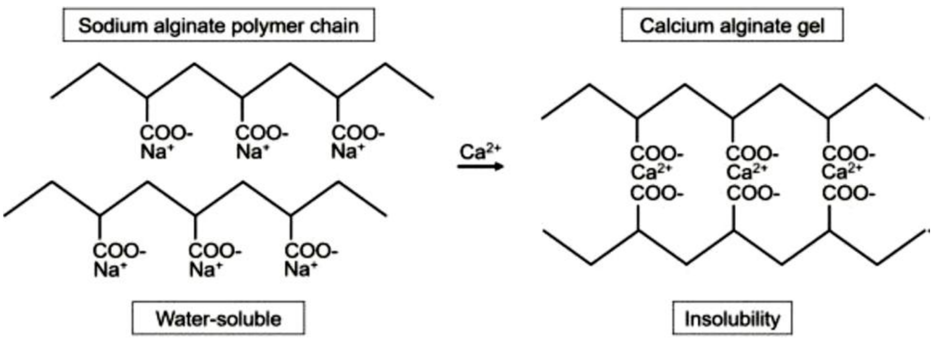
- **Material identification and recovery**: AI analyzes images and spectral data to identify plastics, metals, and hazardous materials, resulting in better separation and higher recovery of valuable resources.
- **Prediction and monitoring of e-waste generation**: AI models predict future e-waste trends based on product life cycles, helping governments and industries plan recycling facilities and waste management strategies
- **Detection of hazardous components**: AI systems detect harmful materials like lead, mercury, and cadmium in e-waste. Early identification reduces environmental pollution and protects workers' health.
- **Improving recycling efficiency**: AI helps optimize recycling processes, reduce energy consumption, and lower operational costs in recycling plants.
- **Policy support and decision making**: AI helps in designing better regulations, tracking illegal e-waste dumping, and promoting sustainable e-waste management practices.

Q9b. Discuss the synthesis and properties of alginate hydrogel with reference to its applications in brain–computer interfaces (BCIs).

Alginate is a natural polysaccharide extracted from brown seaweed.

Synthesis of Alginate Hydrogel

- Alginate is first dissolved in water to form a **sodium alginate solution**.
- The hydrogel is formed by adding **calcium ions** (Ca^{2+}).
- Calcium ions crosslink the alginate chains through an **"egg-box" structure**.
- This ionic crosslinking converts the liquid alginate solution into a **stable gel**.
- The process occurs under **mild conditions**.



Properties of Alginate Hydrogel (any 4)

- **Biocompatibility:** non-toxic and well tolerated by brain tissue
- **High water content:** mechanical softness of neural tissue
- **Porous structure:** Allows diffusion of ions and signaling molecules

- **Electrical ion conductivity:** Supports ionic charge transport
- **Minimal inflammatory response:** Reduces damage at the brain–electrode interface.

Applications of Alginate Hydrogel in BCIs (any 4)

- **Soft coating on neural electrodes** to reduce mechanical mismatch with brain tissue.
- **Long-term signal stability** by minimizing scar tissue formation.
- Acts as **conductive interface** when combined with conductive polymers
- Supports **cell encapsulation**, enabling neuron growth near electrodes
- **Implantable neural probes** for recording and stimulation.

Q9c. Explain the extraction of gold from e-waste using the bioleaching method

Extraction of gold from e-waste by the bioleaching method

Bioleaching method is an eco-friendly alternative to conventional chemical processes.
It uses *microorganisms* to dissolve metals under mild conditions.

- **Pretreatment of e-waste**: PCBs are first crushed and ground into small particles making the metals accessible to microbes.
- **Selection of microorganisms**: Bacteria such as ***Acidithiobacillus ferrooxidans*** and ***Acidithiobacillus thiooxidans*** are commonly used. These microbes do not dissolve gold directly but help generate leaching agents.
- **Generation of leaching agents**: The bacteria oxidize ferrous ions and sulfur compounds to produce ***ferric ions*** and ***sulfuric acid***, which act as oxidants.
- **Dissolution of base metals**: Copper and other base metals surrounding gold are dissolved first.
- **Indirect gold solubilization**: Gold is then leached using biologically generated oxidants along with complexing agents such as **cyanide** or ***thiosulfate***

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4[Au(CN)_2]^- + 4OH^-$$

- **Recovery of gold**
  Dissolved gold complexes are recovered by adsorption, precipitation, or electrochemical methods to obtain metallic gold.

Advantages of Bioleaching

- Eco-friendly
- Cost-effective and sustainable.
- Can recover other metals like copper, nickel, cobalt
- Operates under ambient temperature and pressure.

Q10a. Explain the effects of e-waste on the environment and human health

<u>Environmental Effects of E-Waste</u>

- **Soil and water contamination**: Heavy metals like lead, mercury, and cadmium leach from e-waste into soil and groundwater, reducing soil quality and polluting water sources.
- **Air pollution**: Open burning and improper recycling release toxic gases and fine particles, causing air pollution and environmental damage.
- **Damage to ecosystems**: Toxic substances from e-waste enter rivers and lakes, harming aquatic life and disturbing food chains.

<u>Effects of e-waste on human health</u>

- **Respiratory and skin problems**: Inhalation of toxic fumes and direct contact with e-waste can cause breathing difficulties, skin irritation, and allergies.
- **Nervous system and organ damage**: Exposure to heavy metals affects the brain, kidneys, and liver, leading to long-term health issues.
- **Cancer and developmental risks**: Long-term exposure to e-waste toxins increases cancer risk and can affect growth and brain development in children.
- **Immune System Suppression**: Toxic chemicals impair immune response, making people more vulnerable to infections.

Q10b. Explain green synthesis of ZnO nanoparticles and mention its uses in magnetic Radio Frequency Identification (RFID)

<u>Green synthesis of ZnO nanoparticles</u>

- **Preparation of plant extract**: Fresh plant leaves are washed, dried, and boiled in distilled water. The extract is used as a natural reducing and stabilizing agent.
- **Preparation of zinc precursor solution**: zinc nitrate or zinc acetate is dissolved in distilled water
- **Mixing of solutions**: The plant extract is added slowly to the zinc salt solution
  Reaction and precipitation: The mixture is heated and stirred, leading to the formation of a Zn-based precipitate due to reduction of Zn^{2+} ions.
- **Separation and washing**: The precipitate is filtered or centrifuged and washed with distilled water to remove impurities.
- **Drying and calcination**: The product is dried and then calcined at moderate temperature to obtain crystalline ZnO nanoparticles by an eco-friendly route.

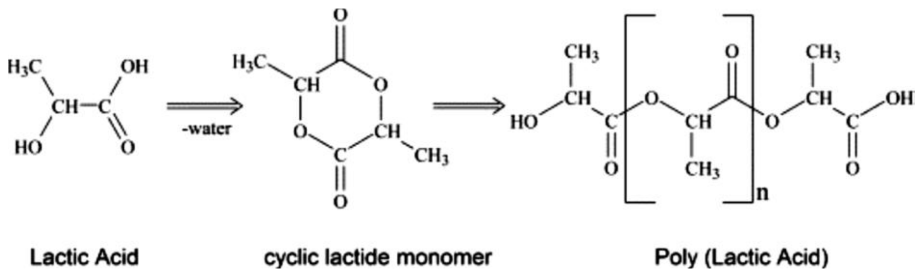
Uses in magnetic RFID and IoNT applications

- **RF signal sensing and response**: ZnO help in sensing and responding to radio frequency signals used in RFID systems.
- **RFID tag components**: fabrication of small and lightweight RFID components without loss of performance.
- **Magnetic and electromagnetic interaction**: ZnO shows good interaction with electromagnetic fields, improving signal detection in magnetic RFID devices
- **Nano-sensors in IoNT**: ZnO nanoparticles act as sensing elements in IoNT systems

Q10c. Explain the synthesis and properties of polylactic Acid (PLA) and its uses in touch screen applications

Synthesis of Polylactic Acid (PLA)

- **PLA** is synthesized from ***lactic acid***, which is produced by fermentation of corn starch or sugar.
- Lactic acid molecules are first converted into a cyclic compound called ***lactide***.
- This lactide is then polymerized by ***ring-opening polymerization*** to form high-molecular-weight **PLA**.



Properties of PLA

- Biodegradable and environmentally friendly.
- Good transparency and optical clarity.
- High mechanical strength and good film-forming ability.
- Lightweight with moderate thermal stability.

Uses of PLA in touch screen applications

- Used as a transparent substrate in touch screen components.
- Applied as protective films and coatings on touch panels.
- Helps reduce environmental impact while maintaining display quality.