Internal Assessment Test 1 – ODD SEM 25-26

Subject: Applied Chemistry for Smart Systems (CSE)

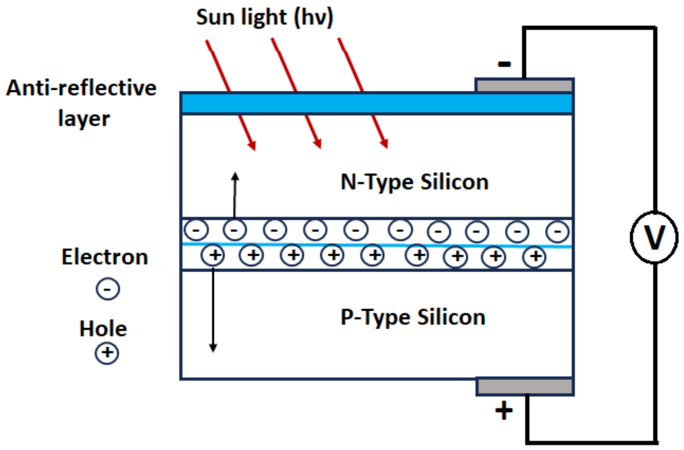
Subject Code: 1BCHES102

Q 1 (a) What are photovoltaic cells? Explain construction and working of PV cells and mention its 2 advantages

Photovoltaic (PV) cells are semiconductor devices that convert sunlight directly into electricity using the photovoltaic effect.

Construction

- **Semiconductor Material**: Usually silicon (Si) in crystalline form
- **P-N Junction**: A junction between p-type and n-type silicon that creates an electric field.
- **Antireflective Coating (TiO_2)**: Reduces light reflection and enhances absorption.
- **Metal Contacts**: Allow current flow and external circuit connection.
- **Encapsulation & Glass Cover**: Protects the cell from environmental damage.



Working

- **Sunlight Absorption**: Photons strike the semiconductor, exciting electrons.
- **Electron-Hole Pair Generation**: Excited electrons move to the conduction band, creating charge carriers.
- **Charge Separation**: The built-in electric field moves electrons to the n-side and holes to the p-side.
- **Electric Current Generation**: Free electrons travel through an external circuit from n-type to p-type for recombination with holes again to generate electricity.

Advantages

- **Renewable energy source:** They convert sunlight directly into electricity, which is abundant and inexhaustible.
- **Environmentally friendly:** PV cells produce no greenhouse gases or air pollutants during operation.

Q 1(b) Define corrosion. Explain the electrochemical theory of corrosion taking rusting of iron as example.

Metallic Corrosion

Metallic corrosion is the gradual degradation of metals due to chemical or electrochemical reactions with their environment.

Electrochemical Theory of Corrosion

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: $Fe \rightarrow Fe^{2+} + 2\,e^-$
- 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: $O_2 + 4H^+ + 4e^- \rightarrow \mathbf{2H_2O}$
- In neutral or slightly basic conditions, the reaction is:
  $O_2 + 2\,H_2O + 4e^- \rightarrow \mathbf{4\,OH^-}$

Formation of Rust (Hydrated Iron Oxide):

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

Q 2 (a) Define battery. Describe construction and working of Na -ion battery and mention its advantages for EV applications (min 4).

Battery

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

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.

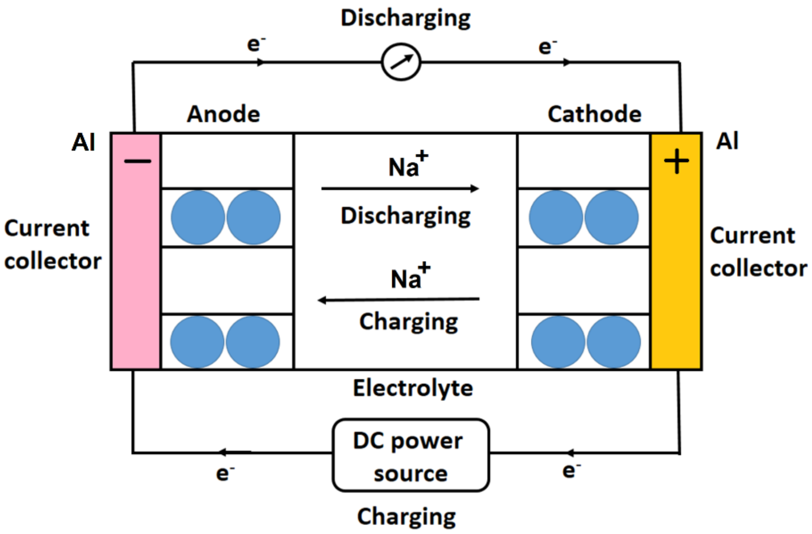
Working Principle

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 :** $\mathrm{NaC} \rightarrow \mathrm{C} + \mathrm{Na}^+ + e^-$
- **Cathode** $\mathrm{Na}_{1-x}\mathrm{MO}_2 + x\mathrm{Na}^+ + xe^- \rightarrow \mathrm{NaMO}_2$

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** $\mathrm{NaMO}_2 \rightarrow \mathrm{Na}_{1-x}\mathrm{MO}_2 + x\mathrm{Na}^+ + xe^-$
- **Anode** $\mathrm{C} + \mathrm{Na}^+ + e^- \rightarrow \mathrm{NaC}$



EV Applications of sodium-ion battery

- Serve as an **alternative power source** for EVs
- Provide **good safety and thermal stability**
- Suitable for **short-range and low-speed EVs**
- Offer **sustainability and resource availability**

Q 2(b) Define concentration cell. The EMF of concentration cell, constructed by combining two silver rods immersed in silver nitrate solution is 0.250 V at 25^{0}C. If concentration of anodic compartment is 0.002 M, calculate the concentration of cathodic compartment. and write the cell reactions

Concentration cell

The concentration cells consist of identical electrodes immersed in the solutions of the same electrolytes but with varying concentrations. The potential difference arises due to differences in electrolyte concentration.

Cell representation: Ag|$AgNO_3$(0.002M) || $AgNO_3$ (C2) |Ag

Ecell = 0.250 V

Temperature (T) = 25°C = 298 K

Concentration of anodic compartment (C_1) = 0.002 M

Concentration of cathodic compartment (C_2) =?

Cathode reaction: $Ag^+ + e^- \longrightarrow Ag(s)$,

Anode reaction: $Ag(s) \longrightarrow Ag^+ + e^-$

number of electrons n = 1

$$E_{cell} = \frac{0.0591}{n} \log \frac{C_{cathode}}{C_{anode}}$$

$$0.250 = 0.0591 \log \frac{C_2}{0.002}$$

$$\log \frac{C_2}{0.002} = \frac{0.250}{0.0591} = 4.23$$

$$\frac{C_2}{0.002} = 10^{4.23} = 1.70 \times 10^4$$

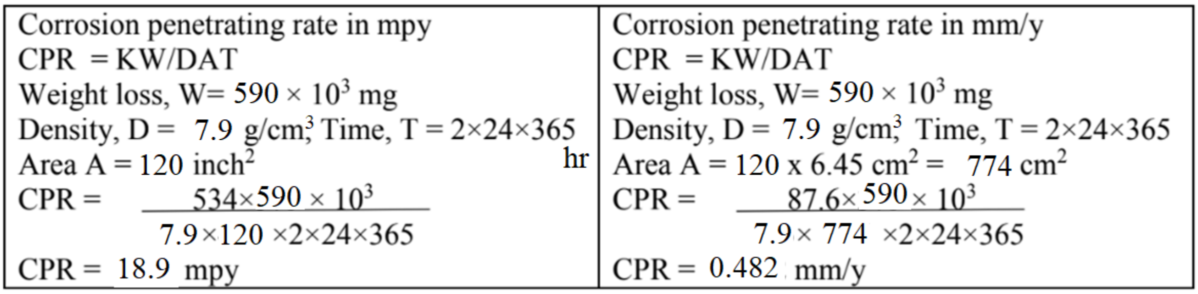
$$C_2 = 0.002 \times 1.70 \times 10^4 = 34.0\, M$$

Q 3(a) Define corrosion penetration rate (CPR). A thick steel sheet of area 120 inch2 is exposed to air near the ocean. After 2 years it was found to experience a weight loss of 590 gm due to corrosion. Calculate CPR in mpy and mmy. [Density of the metal is 7.9 gm/cm3, K(mpy) = 534 and K (mm/y) = 87.6].

The speed at which any metal in a specific environment deteriorates due to a chemical reaction in the metal when it is exposed to a corrosive environment.

The CPR is calculated as follows:

CPR = (K x W) / (D x A x T)



Corrosion penetrating rate in mpy	Corrosion penetrating rate in mm/y
CPR = KW/DAT	CPR = KW/DAT
Weight loss, W= 590×10^3 mg	Weight loss, W= 590×10^3 mg
Density, D = 7.9 g/cm^3; Time, T = $2\times24\times365$ hr	Density, D = 7.9 g/cm^3; Time, T = $2\times24\times365$
Area A = 120 inch^2	Area A = 120 x 6.45 cm^2 = 774 cm^2
CPR = $\frac{534\times590 \times 10^3}{7.9\times120 \times2\times24\times365}$	CPR = $\frac{87.6\times 590 \times 10^3}{7.9\times 774 \times2\times24\times365}$
CPR = 18.9 mpy	CPR = 0.482 mm/y

Q 3(b) Identify and explain the types of corrosion taking place in following case
(i) Tin-Copper Solder Joints in electronic circuits
(ii) Half filled steel water tank

i) Tin–Copper Solder Joints in Electronic Circuits

Type of corrosion: *Dissimilar metallic corrosion (Galvanic corrosion)*

Explanation:

- Tin (Sn) and copper (Cu) are dissimilar metals joined together in solder joints.
- When the joint is exposed to moisture an electrochemical cell forms.
- The metal with the lower electrode potential (copper) acts as the **anode** and corrodes, while tin acts as the **cathode** and is protected.
- The reaction at the anode (copper side) involves oxidation:

$$Cu \rightarrow Cu^{2+} + 2e^-$$

- This results in gradual deterioration of the copper near the solder joint, leading to poor electrical contact and circuit failure.

(ii) Half-Filled Steel Water Tank (3 marks)

Type of corrosion: Water-line corrosion (*Differential aeration corrosion)*

Explanation:

- The steel surface inside the tank is partly immersed in water and partly exposed to air.
- The area just below the water level has **less oxygen** compared to the portion above it, creating a differential oxygen concentration.
- The region with **lower oxygen** becomes the **anode** and corrodes, while the region with higher oxygen becomes the **cathode**.
- The anodic reaction:

$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

- The cathodic reaction (in the aerated zone):

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$$

- Rust forms mainly at the waterline where this oxygen difference is greatest.

Q 4 (a) Explain the construction, working, and applications of a solid oxide fuel cell (SOFC). Discuss its limitations.

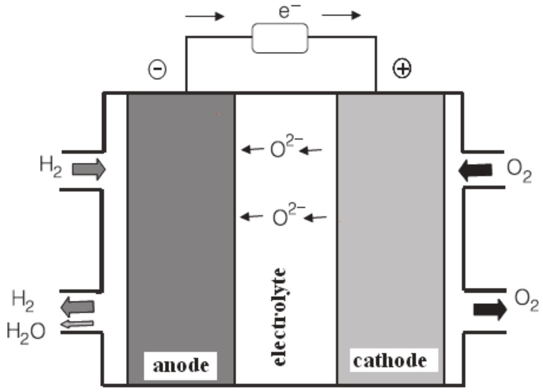
Solid Oxide Fuel Cell (SOFC)

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

Limitations of SOFC

- **High Operating Temperature:** 600–1000°C causes material degradation
- **Material Stability:** Ceramic materials can crack due to thermal stress
- **Cost:** Expensive materials and manufacturing processes
- **Durability Issues:** Long-term operation can degrade electrodes and electrolyte

Q 4(b) Construction and working of ultra-small asymmetric super capacitor and its applications in IoT/wearable devices.

Construction of Ultra-small asymmetric supercapacitor

Electrodes:

- Positive electrode (faradaic): Metal oxides (MnO_2)
- Negative electrode (EDLC-type): Activated carbon

Electrolyte: gel electrolyte (PVA-H_3PO_4)

Separator: A thin ion-permeable membrane (cellulose nanofibers) between electrodes to prevent short-circuiting while allowing ion flow.

Substrate: Built on a flexible or rigid substrate like glass or polyimide film.

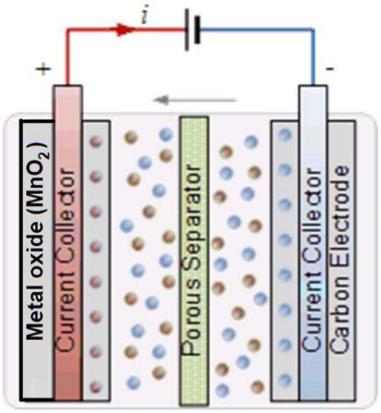
Encapsulation: The entire cell is encapsulated with thin protective layers to prevent moisture degradation.

Working Principle

Charging Process

- At the positive electrode (battery-type), ions from the electrolyte participate in reversible redox reactions, storing charge ***faradaically***.
- At the negative electrode (carbon-based), charge is stored ***electrostatically*** by forming an electric double layer at the electrode–electrolyte interface.
- Electrons move from the negative to the positive electrode.

$$\mathrm{MnO_2} + M^{+} + e^{-} \leftrightarrow MnOOM$$



Discharging Process

- The stored charges are released: the redox reactions at the positive electrode reverse, while the electric double layer at the negative electrode collapses, allowing current to flow through the external circuit. Ions return to their original positions.

Applications in IoT Devices

- Powering low-energy IoT sensors
- Providing backup power for wireless communication modules.

Applications in Wearable Devices

- Power supply for smart watches, fitness trackers, and health-monitoring bands.
- Backup power for medical wearables like ECG or glucose monitors.

Q 5(a) Explain production of green hydrogen by photocatalytic water splitting and mention its advantages.

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.
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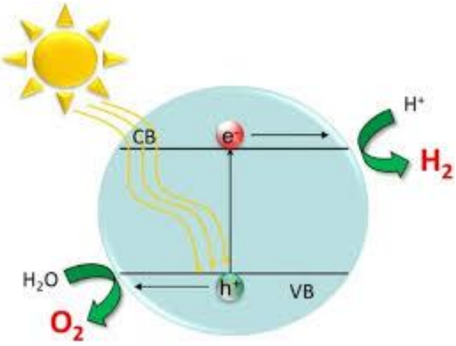


Redox Reactions on Catalyst Surface:

- **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.

Q 5(b) Define fuel Cell. Differentiate between battery and fuel cell.

Fuel Cell

A fuel cell is an electrochemical device that ***converts chemical energy directly into electrical energy*** using a fuel (usually hydrogen) and an oxidant (usually oxygen), without combustion.

Difference Between Fuel Cell and Battery

Feature	**Fuel Cell**	**Battery**
Energy Source	External supply of fuel (e.g., hydrogen) and oxidant	Stores chemical energy internally
Rechargeability	Not recharged; refuelled by adding fuel	Rechargeable or non-rechargeable
Efficiency	High (up to 60% or more)	Moderate to high (depends on type)
Pollution	Zero emissions (with hydrogen fuel)	Generate waste on disposal
Maintenance	Higher; sensitive to fuel purity	Lower
Common Use	Vehicles, backup power, space missions	Phones, laptops, EVs, remote controls

Q 6(a) What are sensors? Explain the working principle of electrochemical gas sensors for detecting SOx and NOx in an air sample

Sensors

- 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.

Electrochemical Gas Sensor for SOx and NOx Detection

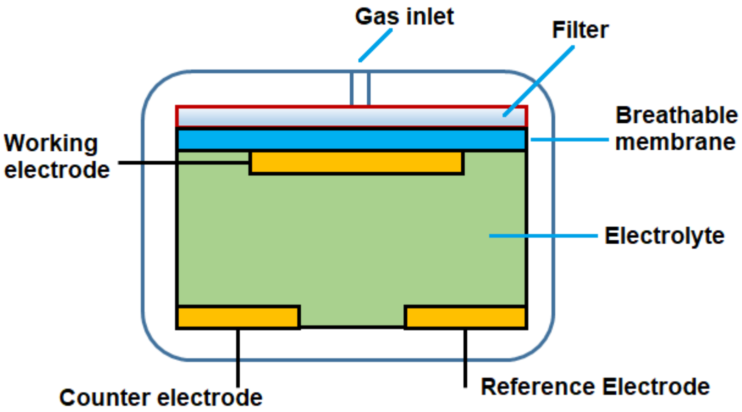
Electrochemical gas sensors detect toxic gases like sulfur oxides (SOx) and nitrogen oxides (NOx) by measuring the electrical current generated from the **redox (oxidation-reduction) reactions** of these gases at an electrode surface.

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

Working principle

- **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.

6(b) What is anodization? Explain the process and its applications in corrosion prevention.

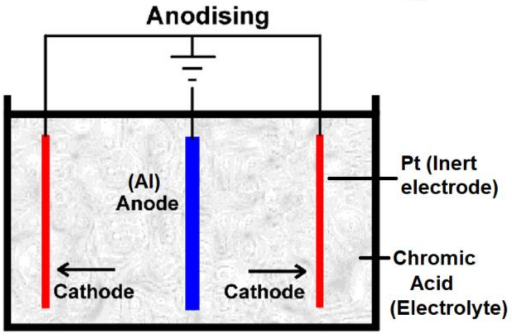
Anodization is the process of oxidation of the outer layer of metal to its metal oxide by electrolysis. The metal oxide layer formed through anodization serves as a protective barrier between the metal substrate and the surrounding environment.

Cleaning: The aluminum surface is cleaned with alkaline or acidic solutions to remove dirt, grease, and oxides.

Electrolytic Bath: The aluminum workpiece is placed in an electrolyte solution (usually chromic acid) and connected to the **anode** in an electrolytic cell.

Electrolysis: When current is passed through the electrolyte, oxygen is released at the aluminum surface, reacting with the metal to form a thick **aluminum oxide (Al_2O_3)** layer.

Sealing: The porous oxide layer is sealed by immersing the anodized aluminum in hot water to close the pores, improving corrosion resistance.



Cell Reaction

Anode reaction: $2Al + 3H_2O \rightarrow Al_2O_3 + 6H^+ + 6e^-$

Cathode reaction: $6H^+ + 6e- \rightarrow 3H_2$

Overall: $2Al + 3H_2O \rightarrow Al_2O_3 + 3H_2$

Applications:

- **Aerospace Industry:** Used in aircraft components
- **Automobile Industry:** Used in car parts
- **Electronics:** in smartphone casings
- **Architectural Applications:** Used in window frames, doors

Q 7(a) Describe the principle and working mechanism of a biosensor for glucose detection in biofluids.

Principle

- A glucose biosensor detects glucose concentration by converting the biochemical reaction of glucose with an enzyme into an electrical signal.
- It is based on the specific enzymatic reaction of glucose with **glucose oxidase** (GOx).
- The enzyme catalyzes the oxidation of glucose, generating a measurable product that correlates with glucose concentration.

Working Mechanism:

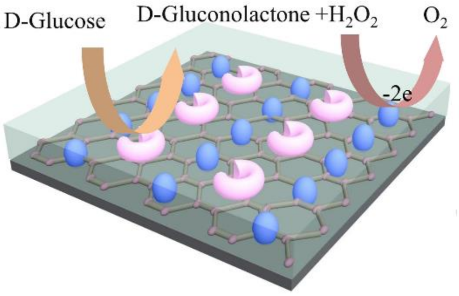
- **Enzymatic Reaction:** Glucose in the biofluid reacts with an enzyme *glucose oxidase* immobilized on the sensor surface (***gold electrode***) placed on graphene layers.

$$\text{Glucose} + O_2 \xrightarrow{GOx} \text{Gluconolactone} + H_2O_2$$

- **Electrochemical Detection:** The hydrogen peroxide (H_2O_2) produced is oxidized at the electrode, generating electrons and producing an electrical current:

$$H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$$

- **Signal Generation:** The electrical current generated is proportional to the concentration of glucose in the sample.
- **Signal Processing:** The current is measured and converted into glucose concentration for display or further analysis.



Q 7(b) What are E-waste? Discuss the effect of E-waste on environment and human health.

E-waste

Electronic waste refers to discarded electrical or electronic devices, such as computers, televisions, mobile phones, and household appliances.

Effects of e-waste on the environment

1. **Soil Contamination**
    - Toxic heavy metals like lead, cadmium, and mercury leach into the soil.
    - Alters soil chemistry, reducing fertility and affecting agriculture.
2. **Water Pollution**
    - Leaching of hazardous substances into groundwater and surface water.
    - Contaminants such as arsenic and chromium disrupt aquatic ecosystems.
3. **Air Pollution**
    - Informal burning of e-waste (to extract metals like copper) releases harmful gases such as dioxins and furans.
    - Contributes to global warming and poor air quality.

Effects of e-waste on human health

1. **Neurological Issues**
    - Lead and mercury exposure can damage the brain and nervous system, especially in children.
2. **Respiratory Problems**

    - Inhalation of toxic fumes from burning plastics and metals causes asthma, bronchitis, and lung cancer risks.
3. **Kidney and Liver Damage**
    - Chronic exposure to heavy metals stresses detoxifying organs, leading to long-term organ failure.

Q 8(a) Discuss the extraction of gold from e-waste using the bioleaching process.

Principle

Bioleaching uses microorganisms to solubilize metals from e-waste. Certain bacteria and fungi produce acids or oxidizing agents that help dissolve metals and form soluble gold complexes.

Pre-treatment: E-waste such as printed circuit boards (PCBs) is crushed, and ground into fine particles to expose the metal surface. Non-metallic materials like plastics are removed.

Bioleaching Process:

- The powdered waste is mixed with a microbial culture such as *Acidithiobacillus ferrooxidans*, *Thiobacillus thiooxidans*
- These microbes oxidize Fe^{2+} to Fe^{3+} or produce cyanide/thiosulfate ions which dissolve gold
- The process is carried out in acidic medium (pH 1.5–3), at 25–35 °C.

Recovery of Gold:

- The gold-containing solution is separated from the solid residue.
- Metallic gold is recovered by adsorption on activated carbon,

Chemical Reactions:

Gold dissolution in chloride medium:

$$Au + 4Fe^{3+} + 4Cl^{-} \rightarrow AuCl_4^{-} + 4Fe^{2+}$$

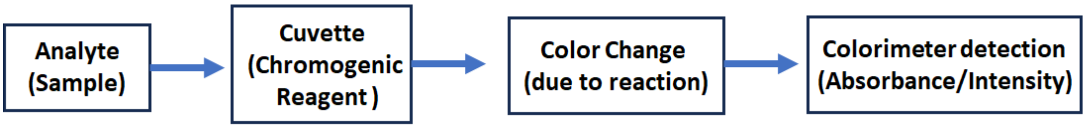
Gold dissolution by cyanide (produced by *C. violaceum*):

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

Q 8(b) What are colorimetric sensor? Discuss their working principle and applications to estimate Copper from PCB

Colorimetric Sensor

A ***colorimetric sensor*** detects the presence or concentration of a target analyte by producing a measurable color change.



Working Principle

- **Initial State**: The sensing material (such as dyes, nanoparticles, or functionalized polymers) has a baseline color (often transparent or a specific color).
- **Exposure to Analyte**: When the sensor comes in contact with the target analyte (gas, liquid, or ion), a chemical reaction or binding event occurs between the analyte and the sensing reagent.
- **Color Change**: This interaction alters the optical properties (absorption or reflectance) of the sensing material, causing a visible color change at specific wavelengths.
- **Detection**: The color change can be observed visually or measured quantitatively using optical devices (like spectrophotometers or cameras).
- **Correlation**: The intensity of the color correlates with the concentration of the analyte.

Applications of Colorimetric Sensors in the estimation of copper in PCB

Colorimetric sensors are used to estimate copper in printed circuit boards (PCB) by measuring the color change produced when copper ions react with a specific reagent to form a colored complex, such as with ammonia. The intensity of the color, measured using a colorimeter or spectrophotometer, is directly proportional to the concentration of copper present. This technique is simple, cost-effective, and allows rapid monitoring of copper during PCB manufacturing, quality control, and recycling.