1a. What are photovoltaic cells? Explain construction and working of PV cells and mention its advantages.

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

Construction:

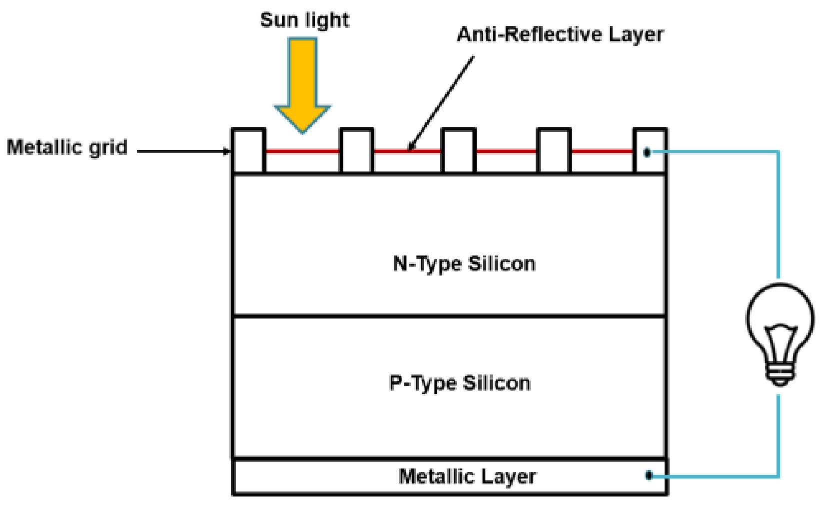
- Photovoltaic Cells consists of p-n junction semiconductor diode made of silicon coated with anti-reflective layer (TiO_2) at the top.
- Two electrical contacts are provided, one in the form of metallic grid at the top of the junction and the other is a silver layer at the bottom of the cell
- The antireflective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

Working of photovoltaic cell:

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

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

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



Advantages of PV cells:

- It is unlimited, inexhaustible and renewable source of energy.
- The solar cell operates reliably for a long period of time with no maintenance.
- Easy to operate
- Quick installation.
- Completely pollution free during its use.

Disadvantages of PV cells:

- High installation cost.
- Energy can be produced only during the day-time.
- The efficiency of solar cells depends on climate.
- Space required to generate unit power output is relatively more.
- Solar cell generates DC current. It needs to be converted to AC for use.

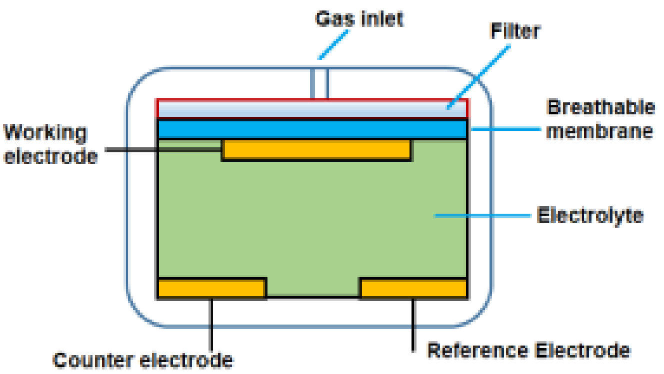
1b. What are electrochemical sensors? Explain their working principle and any 4 applications.

An Electrochemical sensor is a chemical sensor that measures the concentration of a specific substance or analyte in a sample by an electrochemical reaction.

Construction

The components of an electrochemical sensor are:

- Working electrode (sensing electrode): It has direct contact with the sample. An electrochemical reaction occurs on the surface of the sensing electrode.
- Counter electrode: It completes the electrical circuit and helps to measure the current flow through the system during the electrochemical reaction.
- Reference electrode: Provide a stable potential against which the working electrode's potential is measured.
- Breathable membrane: Hydrophobic membrane is used to cover the sensing electrode, it controls the molecular weight of the analyte reaching the electrode surface.
- Filter: to filter out the unwanted analyte.



Working principle of electrochemical sensors

- The principle of an electrochemical sensor is based on the measurement of electrical signals generated as a result of electrochemical reactions occurring on the sensor electrode surface.
- The electrical signal will be proportional to the analyte concentration.
- All electrodes act as a transducer to convert the chemical reaction into a measurable electrical signal.

Applications:

- Widely used in agriculture, food, and oil industries
- Environmental and biomedical applications
- Detection of toxic gases with high selectivity and sensitivity
- Used in water analysis and environmental monitoring

2a. What are thermometric sensors? Describe their working principle and applications.

Thermometric sensor

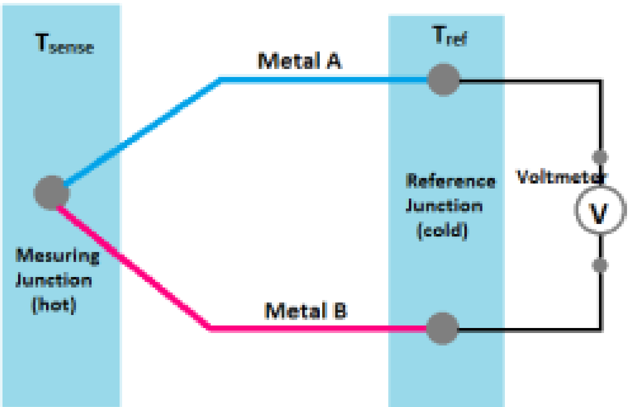
A temperature sensor is a device, typically, a thermocouple or resistance temperature detector, that provides temperature measurement in a readable form through an electrical signal.

Working principle of thermometric sensors

The working principle of a thermometric sensor is based on the concept that the physical properties of materials change with temperature. They are composed of two dissimilar metals that generate an electrical voltage or resistance when a temperature change occurs by measuring the voltage across the diode terminals.

- ***Thermocouples***

In this case, when there is a temperature gradient between the measuring junction and reference junction, a voltage is generated. The magnitude of this voltage depends on the temperature difference between the two junctions and the types of metals used in the thermocouple.



Applications

- Used for verifying design and construction.
- Used to measure the temperature rise during the process of curing concrete.
- They can measure rock temperatures near liquid gas storage tanks
- It can measure water temperatures in reservoirs and boreholes.

2b. Explain the determination of dissolved oxygen (DO) using electrochemical sensor.

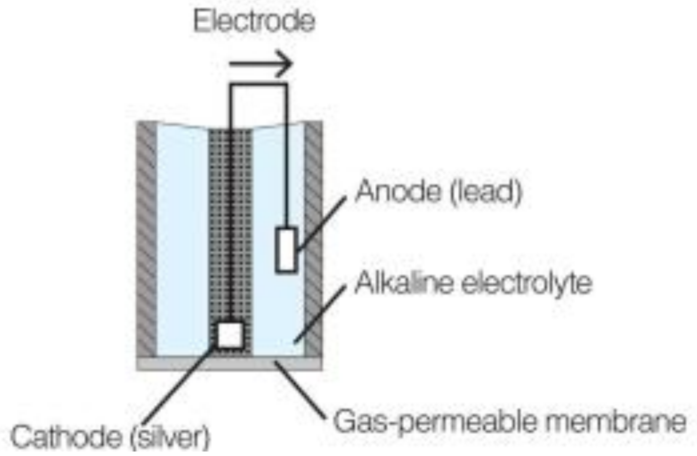
Electrochemical sensors designed for measuring dissolved oxygen typically use a Clark electrode, which consists of a cathode and an anode separated by an electrolyte. The anode serves as a reference electrode, providing a stable potential for the cathode.

Anode: Lead or Zinc

Cathode: Gold or platinum,

Electrolyte: NaOH

Separator: a thin layer of hydrophobic material, such as Teflon.



When the Clark electrode is immersed in a liquid sample, oxygen molecules diffuse through the hydrophobic layer and react with the cathode surface, producing a current that is proportional to the amount of oxygen present in the water.

Anode (Pb): $2Pb \rightarrow 2Pb^{2+} + 4e^-$

Cathode (Ag): $O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$

Overall reaction: $O_2 + 2H_2O + 2Pb \rightarrow 2Pb(OH)_2$

The white solid, $Pb(OH)_2$, that is produced by these reactions is precipitated out into the electrolyte solution. It neither coats the anode nor consumes the electrolyte, and thus does not affect the sensor's performance until the quantity becomes excessive.

Applications

They are widely used in industrial and environmental applications, such as monitoring the oxygen levels in wastewater treatment plants, fish farms, and drinking water supplies.

3a. What are green fuels? Explain the generation of hydrogen using alkaline water electrolysis method.

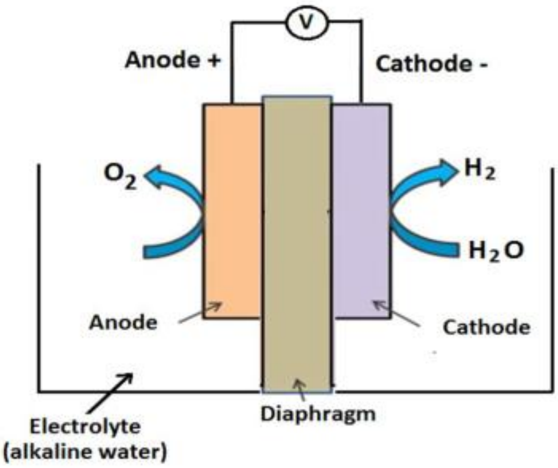
Green fuels are energy sources that can be used as substitutes for traditional fuels, such as diesel and natural gas. These fuels are considered "green" because they have lower carbon emissions making them more environmentally friendly.

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

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

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

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



Advantages

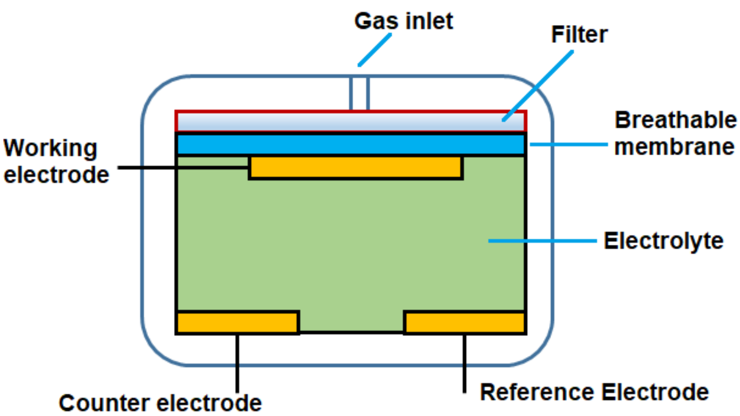
- Well established technology
- Low cost technology
- The energy efficiency is 70–80%
- Commercialized

3b. Construction

- ***Working electrode*** (sensing electrode): **Gold**
- ***Counter electrode***: **Platinum**
- ***Reference electrode***: **Ag/AgCl**
- ***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

- The electrodes are separated and immersed in an aqueous medium (electrolyte).
- The gas molecules diffuse through a porous membrane that is placed in contact with the working electrode.
- In this electrode surface, gas molecules lose electrons after the oxidation process.
- A reduction of oxygen occurs at the counter electrode in electrochemical sensors.
- Electrons move through wires connected to the electrodes and an external circuit.
- Flow of electrons generates an electrical signal proportional to the concentration of toxic gas.
- The medium provides hydrogen ions (H^+) that move through the aqueous solution



Electrochemical reactions for the SO_2 and NO gas sensors are:

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): $(1/2)\,O_2 + 2\,H^+ + 2\,e^- \rightarrow H_2O$

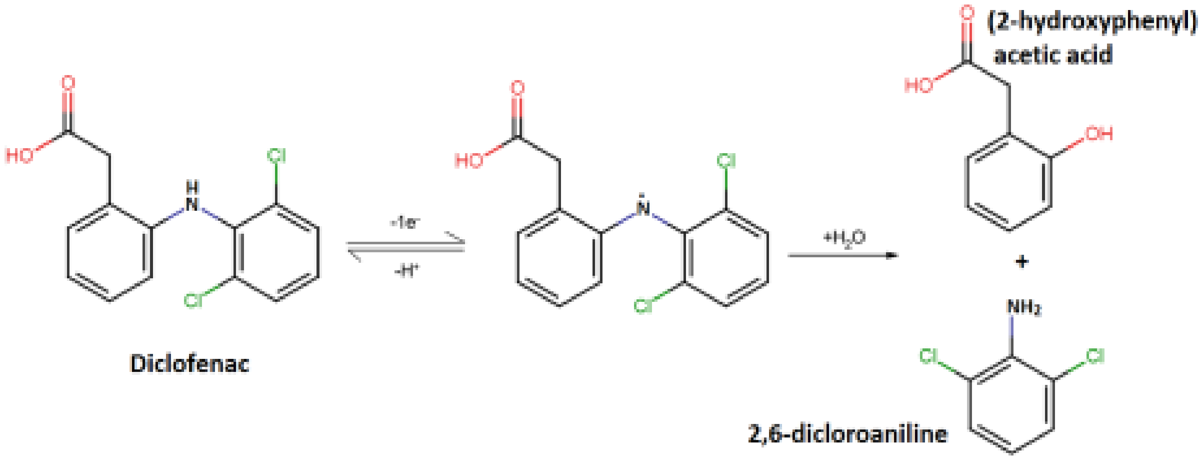
4a. Explain detection of pharmaceutical pollutant using electrochemical sensor.

Construction

- Working electrode: Carbon coated with MWCNT
- Counter Electrode: Platinum mesh (Pt)
- Reference Electrode: Ag/AgCl
- Electrolyte : Aqueous solution of LiCl salt

Working

- When electrochemical sensor is immersed into the sample containing diclofenac drug compound (pH 7.2), an electrochemical oxidation of diclofenac occurs on the surface of the working electrode to which a potential is applied with respect to the reference electrode while the corresponding current is measured.
- The change in potential of the reaction gives the concentration of diclofenac.



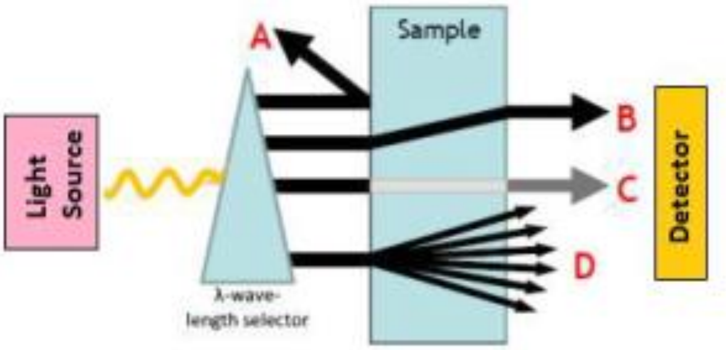
4b. What is optical sensor? Describe its working principle and any 4 applications

Optical sensor

An optical sensor is a device that can detect light, typically at a specific range of electromagnetic spectrum (ultraviolet, visible, and infrared). This sensor can detects various properties of light such as intensity, wavelength, frequency or polarization of light and converts it into an electric signal.

Working principle optical sensor

- ***Transmitter (Light Source)***: Optical sensors have a light source that emits light. This source can be an LED (Light-Emitting Diode) or laser diode.
- ***Interaction with Target***: The emitted light interacts with the target or the environment. This interaction involves reflection, absorption, transmission, scattering, or diffraction of light by the target.
- ***Light Detection (Receiver)***: Optical sensors have a light detector, which can be a photodiode. The detector can sense the change in the properties of the light.
- ***Conversion to Electrical Signal***: The light detector converts the detected optical signals into electrical signals. The amount of change in the electrical signal is related to the properties of the light interacting with the target.



Applications

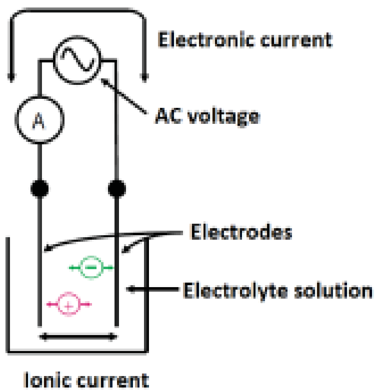
- The following are the applications of optical sensors:
- It is used in remote sensing satellite
- Used in imaging
- Quality and Process Control applications.

5a. Describe the working principle and applications of Conductometric sensors.

A conductivity sensor is a sensor used to measure the conductivity of various solutions or the concentration of the overall ion in a sample. It is based on the measurement of the specific conductance of an analyte.

Construction

- A conductometric sensor consists of two inert metal electrodes.
- Those two electrodes are separated at a certain fixed distance before applying AC voltage, which later causes current flow.
- The sensor is immersed in the conductive liquid which acts as the electrical conductor between the sensor electrodes.



Working principle

The conductance depends on the mobility of ions as well as the number of ions migrating between the electrodes. The basic principle of a conductometric sensor involves a reaction that changes the ionic species concentration. This reaction leads to changes in ionic concentration as well as the conductance between the electrodes. That affects electrical conductivity or current flow. The analyzer applies an alternating voltage to the drive coil, which induces a voltage in the liquid surrounding the coil. The voltage causes an ionic current to flow proportional to the conductance of the liquid.

Applications

- Monitoring the quality of human drinking water
- Monitoring the quality of industrial water
- Battery electrolyte density monitoring
- Making devices for producing electrolytic oxygen and hydrogen

5b. What are disposable sensors. Explain the principle of the disposable sensor in the detection of ascorbic acid.

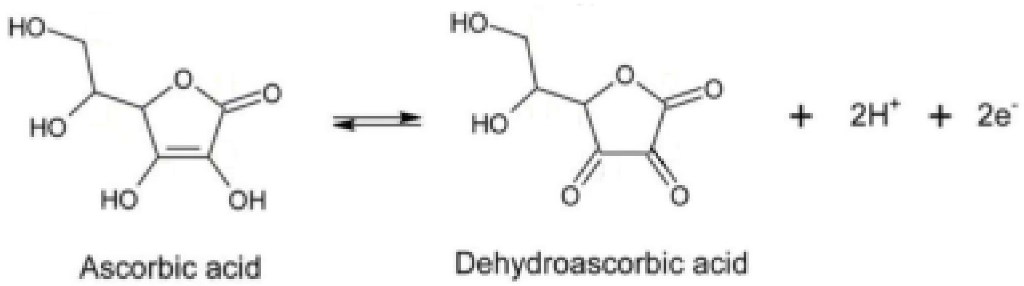
Disposable sensors are low-cost and easy-to-use sensing devices intended for short-term or rapid single-point measurements.

Construction

- Working Electrode: Active materials like CNT/GO printed on the electrode.
- Counter electrode: Platinum mesh (Pt)
- Reference Electrode: Ag/AgCl

Working:

- When the disposable sensor is immersed in the analyte, the analyte diffuses and adsorbed on the sensing electrode.
- The sensing electrode oxidizes ascorbic acid into dehydroascorbic acid and produces electric current and it is proportional to the concentration of the ascorbic acid.



6a. Explain the generation of hydrogen using PEM electrolysis method and mention any 4 advantages.

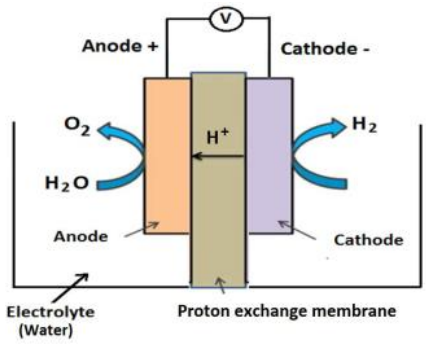
Proton Exchange Membrane (PEM) isolates the anode and cathode to avoid direct contact between oxidation and fuel. The purpose of this membrane to conduct protons only and block the electrons. It incorporates numerous proton conductive functional groups that allow protons to move one side to other.

- In PEM water electrolysis, water is electrochemically split into hydrogen and oxygen at their respective electrodes such as hydrogen at the cathode and oxygen at the anode.
- PEM water electrolysis is accrued by pumping of water to the anode where it is spilt into oxygen (O_2), protons (H^+) and electrons (e^-).
- These protons are travelled via proton conducting membrane to the cathode side.
- The electrons exit from the anode through the external power circuit, which provides the driving force (cell voltage) for the reaction.
- At the cathode side the protons and electrons recombine to produce the hydrogen gas.

At Anode: $2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) + 4e^-$

At Cathode: $4H^+(aq) + 4e^- \rightarrow 2H_2(g)$

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



Advantages

- Compact system design
- Quick Response
- Greater hydrogen production rate with High purity of gases (99.99%)
- Higher energy efficiency (80–90%)
- High dynamic operation

6b. What are the different sources of e-waste, dicuss its characteristics and composition.

***Sources* of e-waste**

- Consumer electronics such as smart phones, laptops, televisions, and household appliances.
- Office equipment such as computers, printers, copiers, and fax machines.
- Medical equipment such as X-ray machines, monitors, and diagnostic equipment
- Electronic toys and games.
- Obsolete technology such as outdated computer equipment, projectors and VCR:
- Discarded or broken electronic devices.

***Composition* of e-waste**

- ***Metals*** such as copper, gold, silver, and aluminium.
- ***Plastic*** components, including casings, insulation, and cables.
- ***Glass components***, such as screens and lenses.
- ***Circuit boards***, which contain a mixture of metals and other materials.
- ***Batteries***, which can contain hazardous materials such as lead, mercury, and cadmium.
- ***Hazardous materials***, such as flame retardants, heavy metals, and polychlorinated biphenyls (PCBs).

***Characteristics* of e-waste**

- **Complexity:** E-waste often contains a complex mixture of materials, making it challenging to recycle and dispose of properly.
- **Hazardousness** such as heavy metals, flame retardants, and batteries, can pose significant environmental and health risks including soil and water contamination, air pollution, and harm to human health.
- **Global issue:** the electronic devices are manufactured, used and discarded worldwide.
- **Resource depletion:** The extraction of raw materials for electronic devices contributes to resource depletion.

7a. Discuss the pyrometallurgical and hydrometallurgical methods of recycling of e-waste.

Hydrometallurgical extraction:

Hydrometallurgical extraction is a process used to extract valuable metals and minerals from electronic waste using chemical reactions and water-based solutions. This process involves the following steps:

- **Collection and sorting**: Electronic waste is collected and sorted into different categories based on the materials present.
- **Shredding or grinding**: The electronic waste is shredded or ground into small particles to increase the surface area for the extraction process.
- **Leaching**: The crushed electronic waste is then treated with a solution, such as sulfuric acid, that dissolves the metals and minerals. This solution is referred to as the leachant.
- **Separation**: The metal-rich solution is then separated from the solid waste. The metals and minerals present in the solution are then recovered using a variety of techniques, such as precipitation, ion exchange, and solvent extraction.
- **Purification**: The recovered metals and minerals are then purified to remove impurities.

Pyrometallurgical methods:

Pyrometallurgical methods of e-waste recycling involve the use of high temperatures to extract metals and minerals from electronic waste. The following are the steps involved in a typical pyrometallurgical process:

- **Collection and sorting**: Electronic waste is collected and sorted into different categories based on the materials present.
- **Shredding or grinding**: The electronic waste is shredded or ground into small particles to increase the surface area for the extraction process.
- **Smelting**: The shredded electronic waste is then heated in a furnace, along with a fluxing agent, to extract the metals. The fluxing agent helps to separate the metals from the other components of the waste.

- **Separation**: The melted waste is then cooled, and the metals are separated from the slag (non-metallic waste) using a variety of techniques, such as skimming, tapping, and slag fuming.
- **Purification**: The extracted metals are then purified to remove impurities.

7b. Write a note on the toxic components present in E-Waste, discuss their health hazards.

The manufacturing of electronic and electrical products often involves the use of toxic materials that can be harmful to human health and the environment. Some of the most commonly used toxic materials include:

- **Lead**: Lead is commonly used in the manufacture of batteries and as a component of solder on printed circuit boards. Lead is a toxic heavy metal that can cause serious health problems, including neurological damage and developmental disorders.
- **Cadmium**: Cadmium is used in the manufacture of rechargeable batteries, as well as in electronic components such as capacitors and resistors. Cadmium is a toxic heavy metal that can cause cancer and other health problems.
- **Mercury**: Mercury is used in the manufacture of switches, relays, and fluorescent light bulbs. Mercury is a toxic heavy metal that can cause neurological damage and other health problems.
- **Brominated flame retardants**: Brominated flame retardants are used in the manufacture of electronic devices to reduce the risk of fire. Some types of brominated flame retardants are toxic and can harm human health and the environment.
- **Phthalates**: Phthalates are used as plasticizers in the manufacture of electronic devices. Some types of phthalates are toxic and can harm human health and the environment.