MODULE-2

Energy, Storage and Conversion

Batteries- Definition, difference between battery and cell. Classification of batteries- primary & secondary batteries. Battery characteristics.

Secondary batteries - construction, working and industrial applications of Lead- acid battery and Nickel-metal hydride battery.

Modern batteries: Construction, working and industrial applications of Li-ion battery.

Fuel Cells- Introduction, definition, construction, working and industrial applications of H_2-O_2 fuel cell & methanol-oxygen fuel cell. Differences between battery and fuel cell.

Green fuels: Power alcohol-introduction, advantages and disadvantages.

Biodiesel- Introduction, synthesis, advantages, and disadvantages.

E-waste management: Introduction, sources, types, effects of e-waste on environment and human health, methods of disposal, advantages of recycling, extraction of copper and gold from e-waste.

10 hours

Battery Technology

The conversion of chemical energy into electrical energy is a function of cells or batteries. A cell designates a single unit consisting of anode, cathode and an electrolyte. The arrangement of two or more cells connected in series or parallel is called battery.

Principal components of a battery:

The main components of a battery are:

1. Anode: It is a negative electrode where oxidation takes place. It gives out electrons to the external circuit during electrochemical reaction.

2. Cathode: It is a positive electrode where reduction takes place. It accepts electrons from the external circuit.

3. The electrolyte (active mass in the anode and cathode): It is an ionic conductor, typically a solution or slurry of acids, alkalis, or salts with high ionic conductivity.

4. The separator: The material which electronically isolates anodes and cathodes in a battery to prevent internal short circuiting are referred to as separators. They are permeable to the electrolyte so as to maintain desired ionic conductivity. Thus, their main function is to transport ions from the anode compartment to the cathode compartment and vice-versa.

Classification of batteries:

Batteries are classified into two types

a) **Primary batteries:**

These are the batteries in which the cell reaction (chemical reaction) is irreversible. These batteries cannot be recharged or reused because after some times the cell reaction stops and cell becomes dead.

Ex: Zn-MnO_2 battery, Li-MnO_2 battery, etc,

b) **Secondary batteries:**

These are the batteries in which the cell reaction (chemical reaction) is completely reversible. These are also known as rechargeable batteries or reversible batteries. They can be recharged to their original condition by passing the current.

Ex: Lead – acid battery, Ni – Cd battery, etc.

Characteristics of a battery:

A battery is specifically designed, constructed and used based on the following characteristics.

Voltage or emf of the battery:

The voltage available form a battery depends upon the EMF of the cell, EMF depends on constitutes of a battery system. The EMF of a battery is calculated using the Nernst equation

$$E^0_{Cell}=E^0_{cell}+\frac{0.0591}{n}\log\frac{[\text{concentration at cathode}]}{[\text{concentration at anode}]}$$

Where $E^o_{cell} = E^o_{cathode} - E^o_{anode}$

Current:

Current is a measure of the rate at which the battery is discharging. A battery can deliver high current only when there is a rapid electron transfer reaction. Rapid electron transfer reaction is possible when the battery contains large quantities of active materials.

Capacity:

The capacity is the charge or amount of electricity that may be obtained from the battery during discharge and is measured in ampere hours (Ah). Capacity depends on the size of the battery and is determined by Faraday relation-

$$C = \frac{WnF}{M}$$

Where W is weight of the active material, M is the molar mass of the active material, C is the capacity in ampere hours and n is the no. of electrons involved in the reaction.

Cycle life:

It is applicable only to secondary batteries, which can be recharged. Cycle is a single charge and discharge of a secondary/rechargeable battery and the number of charging cycles to discharge cycles that are possible before failure occurs is termed as cycle life. Batteries cycle life must be high.

Energy density:

Energy density is a measure of how much energy can be extracted from a battery per unit weight or volume of a battery.

Power density:

It is a measure of how much power can be extracted from a battery per unit weight of a battery.

Energy efficiency:

It is also known as cell efficiency. It is applicable only for secondary batteries.

The energy efficiency of a storage battery (in percent) is defined as

% energy efficiency = energy released on discharge/ energy required for charge X 100.

It is given by a ratio of energy released on discharge to energy required for charge.

Higher the energy efficiency, better is the battery (batteries should have high energy efficiency). As the energy efficiency increases, then the quality of the battery also increases.

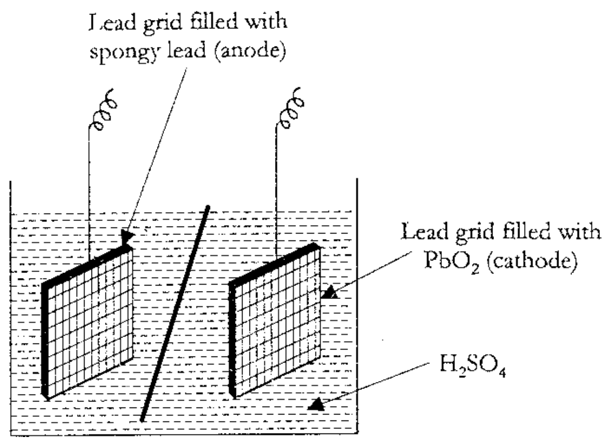
Shelf life or storage life:

Shelf life is the maximum time for which a given battery can be stored without self-discharge or corrosion or loss of performance. Good Shelf life is expected when there is no self-discharge or corrosion. Self- discharge takes place when there is a reaction between the anode and cathode active materials. Self-discharge and corrosion reduce the shelf life of a battery. A good battery is one which has high shelf life or storage life.

Construction, working and applications of some commercially important batteries:

Lead-acid battery:

Construction:



Lead-acid battery consists of two electrodes made of flat grids of lead. The anode grid is filled with a paste of spongy lead metal (Pb) and other additives such as graphite powder (0.25 %), lignin sulphonate (0.2%), and barium sulphate (0.35%). The cathode grid is filled with a paste consisting of equal amount of lead dioxide (PbO_2) and lead. Several such pairs of anode & cathode grids are immersed or dipped alternatively in 5M or 37 % H_2SO_4, which acts as the electrolyte. The anode and cathode grids are separated by micro porous polyethylene separators.

Cell reactions during discharging of the battery:

At Anode, Lead electrode loses electrons, which flow through the external circuit. In this reaction oxidation of lead takes place.

$$Pb \rightarrow Pb^{+2} + 2e \text{------------------- oxidation}$$

$$Pb^{+2} + SO_4^{-2} \rightarrow PbSO_4$$

$$Pb + SO_4^{-2} \rightarrow PbSO_4 + 2e^-$$

At Cathode, PbO_2 undergo reduction.

$$PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{+2} + 2H_2O$$
$$Pb^{+2} + SO_4^{-2} \rightarrow PbSO_4$$

$$PbO_2 + 4H^+ + SO_4^{-2} + 2e^- \rightarrow PbSO_4 + 2H_2O$$

The net cell reaction is: $Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$

Recharging of the battery:

The condition of the battery can easily checked by measuring the density of the solution. When the density falls below 1.20 $gm/cm^{3,}$ the battery needs charging.

The net recharging reaction is,

$$2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2H_2SO_4$$

In general, the charging and discharging reaction is given by

Discharging

$$Pb + PbO_2 + 2H_2SO_4 \longrightarrow 2PbSO_4 + 2H_2O$$

Charging

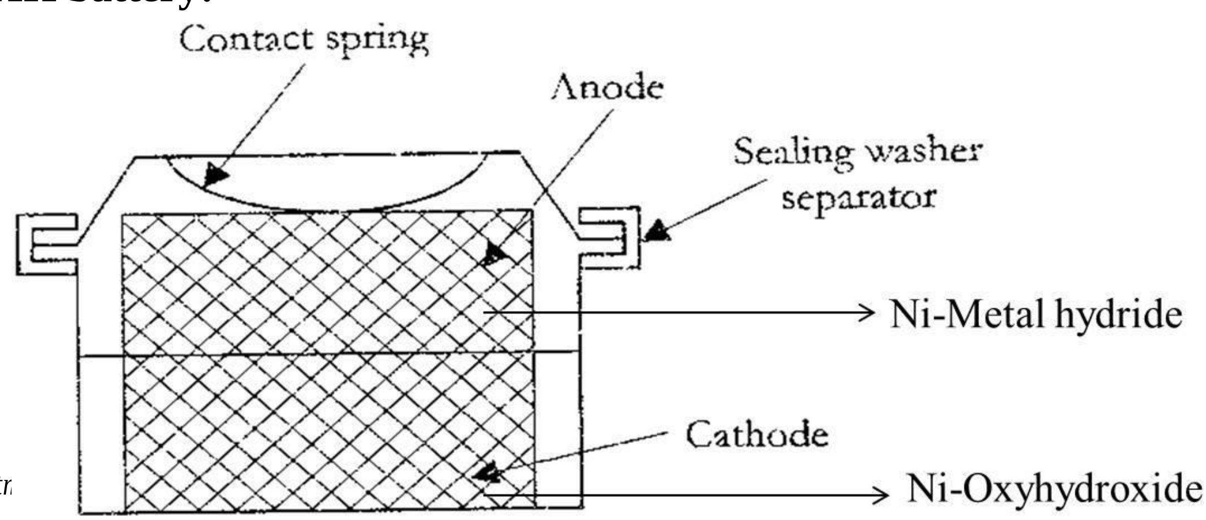
A lead-acid battery produces a potential of about 2.0 V/ cell. A typical 12V lead acid battery consists of six individual cells connected in series.

Applications:

- Lead-acid batteries are widely used in automobiles to start engines.
- They are also used in UPS systems to power computers, as well as in laboratories, hospitals, emergency lighting, telephone exchanges, broadcasting stations, and more.

<u>Modern Batteries</u>

Ni-MH battery:



It consists of rectangular nickel wire gauze grids. The anode grid is coated with a metal-hydride as the active material, while the cathode grid is coated with nickel oxyhydroxide. The anode and cathode grids are separated by a microporous polypropylene separator. Both electrodes are immersed in a 21% KOH solution, which acts as the electrolyte.

Cell reactions during discharging of battery are:

At anode:

$$MH + OH^- \longrightarrow M + H_2O + e^-$$

At cathode:

$$NiOOH + H_2O + e^- \longrightarrow Ni\,(OH)_2 + OH^-$$

The net cell reaction is

$$MH + NiOOH \longrightarrow M + Ni\,(OH)_2$$

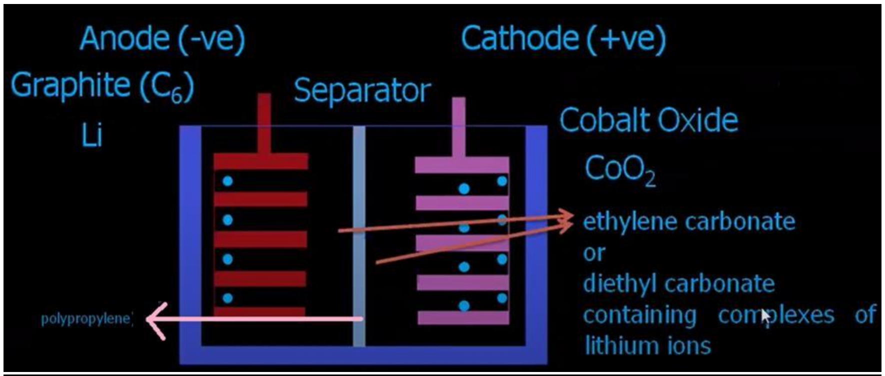
This battery produces a potential of 1.25 v to 1.35v/cell

Applications:

It is used in digital camera, potable music player, cordless phones, cordless mouse, cordless key boards, laptops, electric vehicles, etc.

Lithium ion battery

Diagram



In lithium-ion battery, the anode is made up of layered of graphite which is intercalated (inserted) with lithium, the cathode is made up of cobalt dioxide (CoO_2), these two electrodes are dipped in an electrolyte containing $LiPF_6$ (Lithium hexafluorophosphate) dissolved in ethylene carbonate or diethyl carbonate, these two electrodes are separated microporous poly propylene separator.

Working: During cell discharging

At anode: lithium atoms present in graphite layer is oxidized, which result in the **liberation** of **lithium ion** and e^-. The election flows through the external circuit to the cathode.

At cathode: CoO_2 reduction take place which result in the **insertion** of **lithium** ion in to cobalt oxide layer.

Reaction during discharging

Reaction at Anode: $LiC_6 \rightarrow C_6 + Li^+ + e^-$

Reaction at Cathode: $CoO_2 + Li^+ + e^- \rightarrow LiCoO_2$

Net Cell Reaction: $LiC_6 + CoO_2 \rightarrow C_6 + LiCoO_2$

Advantages

- High energy density because of the low atomic mass of lithium (Atomic number = 3)
- The output potential is above 4V due to the high negative electrode potential of lithium
- This battery work efficiently in a wide range of temperature (-40 to 70 ^{0}C)
- Does not undergo self-discharging
- It has a long memory backup

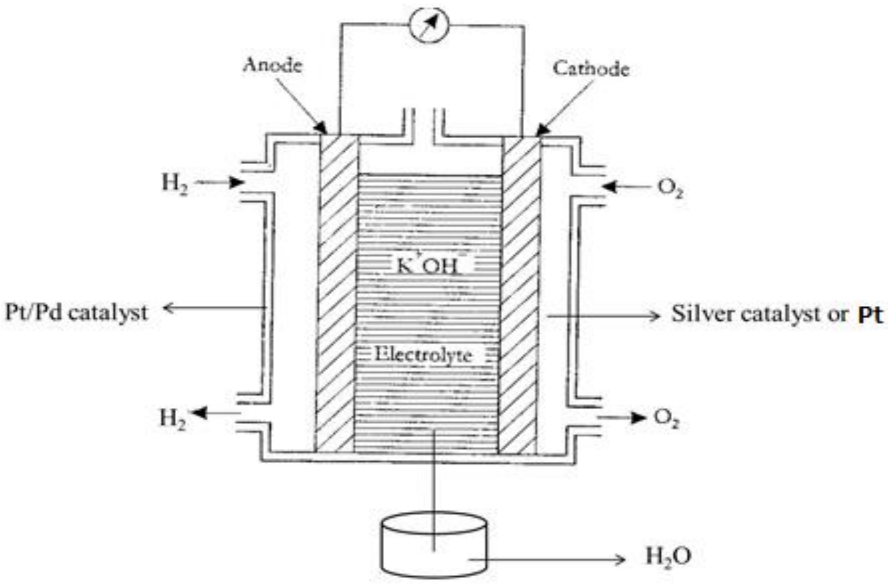
Application

- These are high energy density battery, hence they are used in mobile phone, laptop, electric vehicles, spaces vehicles and other electronic gadgets.
- Because of long memory back up it is used in safety and security devises

FUEL CELLS

Fuel cells are the galvanic cells in which the chemical energy of fuel is directly converted into electrical energy.

H_2 - O_2 fuel cell



In this H_2 - O_2 fuel cell, hydrogen gas is used as a fuel and oxygen gas is used as oxidant. The

H_2 - O_2 fuel cell consists of two electrodes made of porous carbon or graphite. The anode is coated with finely divided platinum or palladium catalyst. The cathode is coated with platinum or silver catalyst. These two electrodes are placed in aqueous solution of KOH (30 %), which acts as electrolyte.

Cell reactions

At anode, hydrogen gas diffuse through the anode, it is absorbed on the electrode surface and reacts with hydroxyl ions to form water

$$2H_2\,(g) + 4\,OH^-(aq) \longrightarrow 4H_2O\,(l) + 4\,e^-$$

At cathode, O_2 diffuses through the cathode (electrode) and reacts with water molecules to form OH^- ions (reduction of oxygen takes place to OH^- ions).

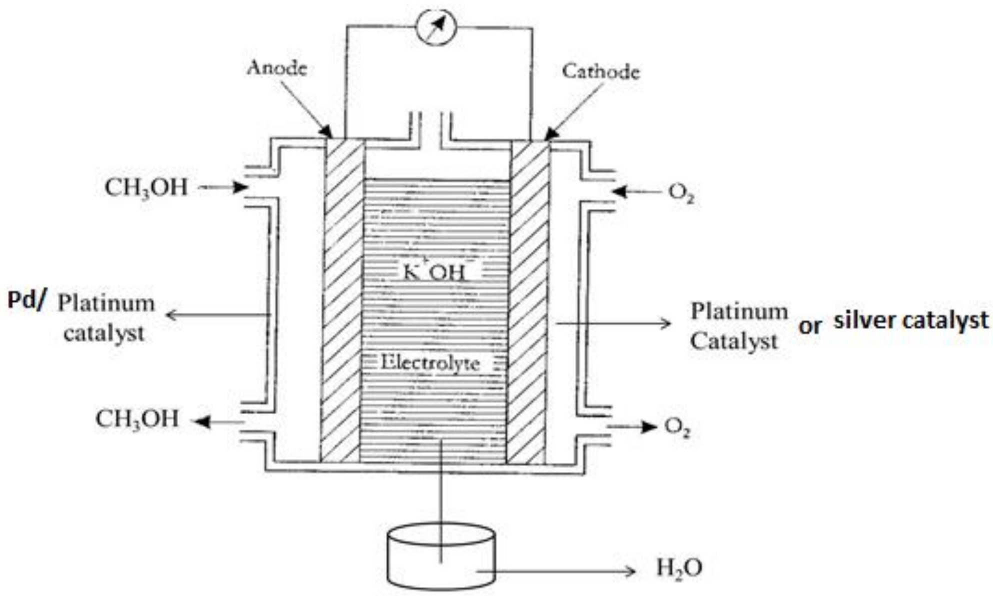
$$O_2\,(g) + 2H_2O\,(l) + 4e^- \longrightarrow 4\,OH^-$$

Net cell reaction: $2\,H_2\,(g) + O_2\,(g) \longrightarrow 2H_2O\,(l)$

The net cell reaction is nothing but the combustion of H_2 and O_2. The water formed as the product, which dilutes the KOH concentration. As a result, the cell becomes inactive. Therefore, the electrolyte is always kept hot so that water evaporates as fast as it is formed. A wick placed inside the electrolyte to maintain proper water balance. The cell produces an EMF of 1.23V.

Uses: It is used as electric power source for space vehicles, military vehicles and mobile power system.

Methanol- O_2 fuel cell:



In this Methanol- O_2 fuel cell, Methanol is used as a fuel and oxygen gas is used as oxidant. The Methanol- O_2 fuel cell consists of two electrodes made of porous Ni. The anode is coated with finely divided platinum or palladium catalyst. The cathode is coated with platinum or silver catalyst. These two electrodes are placed in aqueous solution of KOH (30 %), which acts as electrolyte.

Cell reactions

At anode, Methanol diffuse through the anode, it is absorbed on the electrode surface and reacts with hydroxyl ions to form water.

$$CH_3OH + 6\,OH^- \longrightarrow CO_2 + 5H_2O + 6\,e^-$$

At cathode, O_2 diffuses through the cathode (electrode) and reacts with water molecules to form OH^- ions (reduction of oxygen takes place to OH^- ions).

$$3/2\,O_2 + 3H_2O + 6\,e^- \longrightarrow 6\,OH^-$$

Net cell reaction $$CH_3OH + 3/2\,O_2\,(g) \longrightarrow CO_2 + 2H_2O$$

The cell produces an emf of 1.23V.

Uses: It is used as electric power source for space vehicles, military vehicles and mobile power system

Differences between battery and fuel cell

Sl. No.	Battery	Fuel cell
1.	It is an effective energy storage system i.e. chemical energy is stored in the battery	It is an effective energy conversion system i.e. the energy is not stored in fuel cell.
2.	The reactants are not freely available and hence the production cost is more.	Fuels and oxidants are freely available, hence they are cheaper.
3.	It needs charging again and again.	No need of charging.
4.	The byproducts may be harmful and cause pollution.	Byproducts are eco-friendly and not cause any pollution.
5.	Efficiency of the battery is low	Efficiency of the fuel cell is high
6.	Reactants are used during the construction of battery	Reactants are introduced from outside the cell
7.	Battery operates until the reactants stored in it are completely used up	Fuel cell operates as long as the reactants are supplied to the electrodes from outside
8.	Ex: lead acid battery, Zn- air battery, Ni-Cd battery, etc.	Ex: Hydrogen- oxygen fuel cell. Methane- Oxygen fuel cell, methanol- oxygen fuel cell, etc.

POWER ALCOHOL

Mixing ethanol with gasoline is known as power alcohol. It is primarily used to enhance engine performance and reduce emissions.

The importance of power alcohol as fuel are

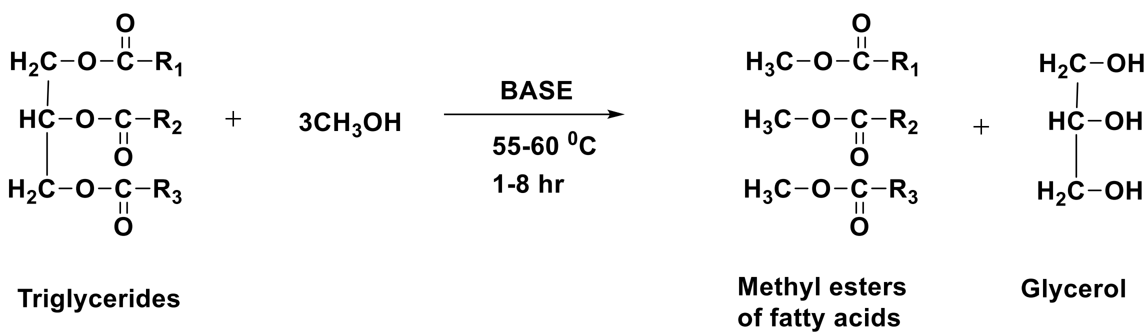
1. Alcohol has an octane number of 90; while petrol has octane number of 60-70. Addition of power alcohol to petrol increases the octane number. Hence alcohol blended petrol possesses better anti-knock properties.
2. There are no starting difficulties with alcohol-petrol blend.
3. Lubrication in case of alcohol-petrol blend and pure petrol is the same.
4. Ethanol is biodegradable.

Disadvantages

1. It lowers the calorific value of petrol (7000 Kcal/Kg, petrol 10,000kCal/Kg)
2. Due to considerable surface tension, alcohol does not atomize at low temperature.
3. Due to oxidation of alcohol in storage tanks, corrosion can occur.

BIO-DIESEL

Biodiesel is prepared from the process of transesterification of vegetable oils contain triglycerides. The transesterification process involves the treatment of the triglycerides in these oils with excess of methanol in the presence of NaOH (Catalyst) at 55-60^{0}C for 1-8 hr which give methyl esters of long chain fatty acids and glycerol [used cooking oil, rendered animal fat etc could also be converted to biodiesel].



Where R_1, R_2 and R_3 are long chain fatty acids. **The mixture of methyl esters are called biodiesel** and have desired characteristics of diesel fuel with cetane number in the range of 50-62. So, this biodiesel can be used as alternative fuel for compression ignition engines or can be blended with petro-diesel and used.

Advantages

1. It is made using renewable sources.
2. Readily undergoes bio degradation.
3. Biodiesel has a higher cetane number (50-60) compare to diesel (40 – 55).
4. Use of biodiesel reduces greenhouse gases.
5. It is nontoxic.

Disadvantages

1. Not used in cold condition
2. Less stable than diesel
3. It may degrade plastics/rubber

E-Waste

Disposable electrical and electronic devices or components are known as E-waste

Examples: TV, Refrigerators, Washing machines, Micro-ovens, Air-conditioners, Computers, Laptops, Mobile phones, and other electronic devices.

Sources and types of E-waste:

The major sources of E-waste are-

I) Major House-hold appliances:

Ex: Refrigerators, Washing machines, Air-Conditioners, TVs, etc.

II) Small House-hold appliances:

Ex: Vacuum Cleaners, Microwaves, Dryers, mixer etc.

III) IT and telecom equipment:

Ex: Computers and their accessories, monitors, printers, TVs, LCDs, laptops etc.

IV) Electrical or electronic devices

Ex: Switches, wires, bulbs, mobile phones, chargers, TV remotes, DVD, CD players, and digital cameras.

V) Toys and solar panels

Ex: All types of electronic children's toys and solar water heaters, solar watches.

VI) Medical devices

Ex: Diagnostic equipment (ultra sound and CT scanners), hearing aids and other instruments.

Effects of e-waste on environment and human health

The e-waste contains a number of toxic components that can cause serious damage to the environment as well as human and animal health, if not properly discarded into the environment.

Sources and ill effects of some heavy metals are given below

Metals	Sources/Occurrence	Ill Effects
i) Mercury (Hg)	Components of Copper-machines, steam iron (iron box), batteries, LCD etc.	Hg and Hg compounds are toxic to the environment and human beings. The inhalation of Hg- vapour can produce harmful effects on the lungs, kidneys, Central nervous system and digestive systems. Symptoms include insomnia, memory loss, neuro-muscular effects and headache. Finally kidney failure.
ii) Cadmium	Batteries, pigments solder, alloys, circuit boards, computer Batteries, cathode ray tubes	Cadmium can cause damage to kidneys and bones. (Because Cd is accumulated in the human kidney and is bio-accumulated in the environment.)
iii) Lead (Pb)	Lead rechargeable batteries, solar cells, stabilizers, lasers, LED's, circuit boards. It is found in computer monitors and televisions	Lead can cause serious damage to human health such as the reproductive systems and nervous systems. it also causes anemia, brain and kidney damage.
iv) As	Semi- conductors, diodes, microwaves LED's (Light emitting diodes) and solar cells.	Causes skin cancer, hyperpigmentation, keratosis and block foot disease.

The improper disposal of E-waste is very dangerous to the environment. Because it affects the soil, air, and water.

<u>Effects of E-waste on Air:</u>

Burning of e-waste at temperatures (900–1000°C) can release hydrocarbons into the atmosphere, polluting the air. For example, open burning of printed circuit boards and electric cables to recover copper releases hazardous organic substances (dioxins, PAHs [Polycyclic Aromatic Hydrocarbons], PCBs [Polychlorinated Biphenyls], and halogenated compounds) into the environment. These substances are highly toxic and can cause numerous health problems."

<u>Effects of E-waste on Water:</u>

E-waste can penetrate from the soil into groundwater, which then flows into surface water. Contaminants such as heavy metals (Pb, As, Cd), dioxins, furans, PAHs, and PCBs can cause human health issues, including gastrointestinal irritation, laxative effects, abnormal sperm quality, chromosomal abnormalities, DNA damage, reduced fertility, and adverse birth effects.

<u>Effect of e-waste on soil :</u> Landfilling is a common method for disposing of e-waste, where waste is buried in trenches and covered with soil. As the e-waste breaks down, it releases toxic heavy metals like lead, arsenic, and cadmium, which can contaminate the soil. These toxins affect plant growth by altering the soil's pH and disrupting nutrient absorption, particularly nitrogen and potassium. When these harmful substances enter the food chain, they pose serious health risks, including birth defects and other health problems.

Landfilling is a widely used method for the disposal of E-waste. In this method trenches are made on flat surfaces and waste materials are buried in them and covered by a thick layer of soil.

As e-waste breaks down, it releases toxic heavy metals. Such as lead, arsenic, and cadmium. When these toxins penetrate the soil, they influence plants and trees. Many of the effluents are acidic and responsible for changing the pH of the natural soil and reducing the yield. If the concentration of Pb, Ba, Ca, Hg, Cr, and Zn are more then it disturbs the nitrogen and potassium absorption by plants, which are important components in plant growth and development. Thus, these toxins can enter the human food supply, which can lead to birth defects and other health complications.

Method of disposing of E-waste

The following methods are used to dispose of e-waste:

Landfilling: This is the most commonly used method of disposing of e-waste. In this method, large trenches are made in the soil to **bury e-waste.**

Incineration: It is also the most commonly used method to dispose of e-waste. In this method, the e-waste is **burned at high** temperatures. But this is also not a good method because when the e-waste burns, it releases harmful gases which harm our environment.

Acid Bath: In this method, the **e-waste is soaked** in powerful acids such as sulphuric, hydrochloric and nitric acid solutions, that remove the metal from the e-waste. The recovered metal is **further reused** to create other products.

Mechanical recycling: This is the most efficient method and also environmentally friendly. In this method, **dry physical separation** is done from the e-waste and recycle them. Precious metals like copper, gold, silver etc., are separated from the e-waste using a **PCB** recycling machine without harming the environment.

E-waste recycling is the process of extracting valuable materials after separation, that could be reused in a new electronic devices.

Advantages of recycling

- Save land space
- Increase affordability
- Recycling Save the environment

- Recycling reduces waste sent to landfills and Incinerators
- Recycling reduces greenhouse gas emission
- Recycling prevents pollution
- Recycling Save natural resources
- Recycling conserves energy

Recycling creates jobs and produces economic benefits

Extraction of copper for e-waste

- **Separation of Metals**: First, e-waste is processed to separate metals like iron, aluminum, copper, lead, tin, and precious metals.
- **Smelting:** The mixed metals are then melted in a furnace (smelter). During this process, copper is separated from other metals like lead, tin, and precious metals, which form a different phase.
- **Refining Copper:** The copper is cast into large slabs (anodes) and refined through an electrochemical process. In this step, pure copper (99.99%) is plated onto a cathode while impurities are left behind.
- **Recovering Valuable Metals:** The leftover residue (slurry) contains valuable metals like gold, platinum, and tin. These metals are recovered using special methods, achieving recovery rates of over 90%.

EXTRACTION OF GOLD FROM E-WASTE.

Gold metal has good electrical conductivity and chemical stability, and hence it is used for making integrated circuits of electronic devices, coating for contacts and connectors.

Among the e-waste. PCBs are rich in metals. It contains around 35% Cu, 0.16% silver. and 0.13% gold.

The most widely used techniques are

Pyrometallurgy and hydrometallurgy

The hydrometallurgical route is more economical.

The hydrometallurgical method involves three stages in metal recovery

1. Pre-treatment stage:

In the pre-treatment step, e-waste is manually dismantled to separate various fractions like metals, ceramics, plastics, wood, and paper, using such as gravity and magnetic separation techniques.

2. Chemical treatment stage

In the chemical treatment step. Targeted metals are leached into the solution by treating with an appropriate leaching agent

Cyanide leaching is the most common method used to extract the gold. Potassium cyanide (KCN) in the presence of oxygen is used as a leaching agent. A water-soluble dicyanoaurate gold complex is obtained in the process.

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

3. Metal recovery stage

Gold is extracted from leached solution by electrodeposition of gold from the dicyanoaurate gold complex. Pure gold metal is taken as cathode and the inert anode is dipped in leached solution. When current is applied, gold is electrodeposited on the cathode.

TEXT BOOKS

1. Engineering Chemistry by M.M.Uppal, Khanna Publishers (2001 edition).

2. A text Book of Engineering Chemistry- by P C Jain and Monica Jain, Dhanapatrai Publications, New Delhi.(2015 edition)

REFERENCE BOOKS

1. Principles of Physical Chemistry B.R.Puri, L.R.Sharma & M.S.Pathania, S.Nagin Chand &Co., (2008 edition).

2. Industrial Chemistry by B. K. Sharma, GOEL Publishing House (2014 edition).

3. Industrial Electrochemistry, Second Edition by Derek Pletcher & Frank C. Walsh publisher: Chapman & Hall, USA (1993 edition).