

1a) When ever a metal is dipped in its own salt solution it has capacity to either loose or gain electrons, due to which it gains some potential which is known as single electrode potential & is represented as 'E'

Nernst equation gives the relation ship between the electrode potential concentration of the species and was derive by a well known scientist Nernst, it was derived by taking well known thermodynamic considerations

Consider a reversible equation



The decrease in free energy is given by Vant hoffs reaction isotherm

$$\Delta G = \Delta G^\circ + RT \ln k \quad 1$$

ΔG = Gibbs free energy ΔG° = Standard gibbs free energy

R = Gas constant T = Temperature k = equilibrium constant

Decrease in free energy represents the maximum work done

$$\text{i.e, } -\Delta G = W_{\max}$$

$$\text{i.e., } W_{\max} = nFE$$

where 'n' is the total number of electrons lost during oxidation or gained during reduction

$$\text{therefore } \Delta G = -nFE \quad 2$$

$$\Delta G^\circ = -nFE^\circ \quad 3$$

k = $\frac{\text{concentration of products}}{\text{concentration of reactants}}$

Substituting 2 & 3 in 1 we get,

$$-nFE = -nFE^\circ + RT \ln \frac{[M]}{[M^{n+}]}$$

Divide the whole equation by $-nf$ we get,

$$E = E^\circ - \frac{RT}{nF} \ln \frac{[M]}{[M^{n+}]}$$

Converting \ln to \log & changing the sign we get

$$E = E^{\circ} + \frac{2.303 RT}{nF} \ln \frac{[M^{n+}]}{[M]}$$

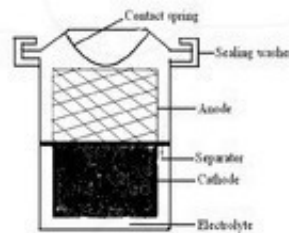
When $T = 25^{\circ}\text{C}$, $R = 8.315\text{Kj/kg}$ & $F = 96500\text{C}$, substituting these in above equation we get

$$E = E^{\circ} + 0.0591 \log \frac{[M^{n+}]}{[M]}$$

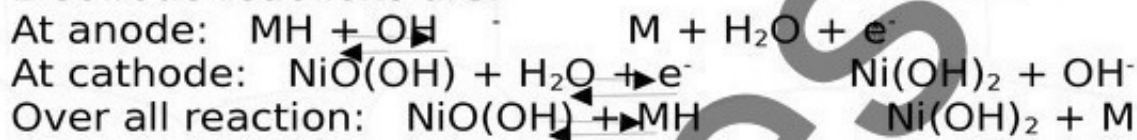
when the concentration of $[M] = 1$, we get

$$E = E^{\circ} + \frac{0.0591}{n} \log [M^{n+}]$$

1c)



Electrode reactions are:



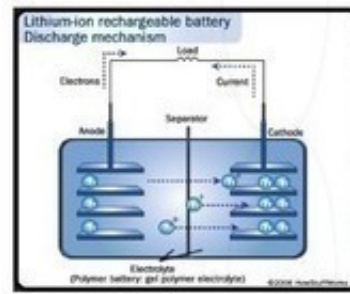
In a Ni-MH cell, a hydrogen storage metal alloy behaves as anode and nickel oxy hydroxide cathode.

- At cathode (a highly porous substrate) nickel oxy hydroxide is impregnated.
- The electrolyte is an aqueous potassium hydroxide solution.
- Synthetic non-woven material used as a separator that separates the two electrodes and behaves as a medium for absorbing the electrolyte

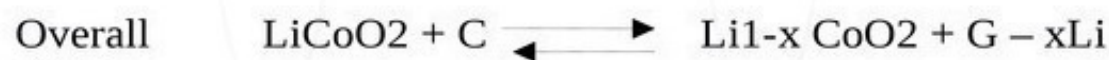
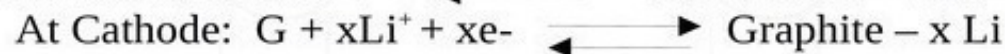
Applications:

- Cellular phones
- Emergency
- Power tools
- Portable electric vehicles

2a)



The chemical reactions for charge and discharge are as shown below:



Construction:

- A lithium-ion rechargeable battery consists of a spiral structure with 4 layers.
- A positive electrode activated by cobalt acid lithium, a negative electrode activated by special carbon, and separator are put together in a whirl pattern and stored in the case.
- It also incorporates a variety of safety protection systems such as a gas discharge valve, which helps prevent the battery from exploding by releasing internal gas pressure if it exceeds the design limit.

Working:

- The lithium ion battery makes use of lithium cobalt oxide (which has superior cycling properties at high voltages) as the positive electrode and a highly-crystallized specialty carbon as the negative electrode.
- It uses an organic solvent, optimized for the specialty carbon, as the electrolytic fluid.

Advantages

- High Energy Density
- High Voltage
- No Memory Effect
- Flat Discharge Voltage
- The Functions of the Safety Circuits (typical functions)
- Long shelf life
- Simple storage and transportation
- Environmentally friendly

Disadvantages:

- Limited service life
- Limited discharge current
- High self-discharge
- High maintenance

2b) Primary batteries are not rechargeable batteries. Cell is operated until the active components in the electrodes are exhausted. Cell reactions are

irreversible. Once all the active components are utilized they do not any further electrical use. They are use & throe batteries. Generally primary batteries have a higher capacity and initial voltage than rechargeable batteries.

Example : Dry cell. Zn-MnO₂, Li - MnO₂ batteries

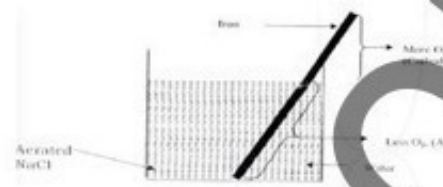
Secondary battery .

Secondary batteries are also called storage cells, because they can be recharged and reused until the shelf life and cycle life of the battery are good, here the cell reactions are reversible and the batteries are recharged by applying direct current in the opposite side of the discharge current

Example: Lead acid battery, Ni MH battery, Ni-Cd battery

2c)

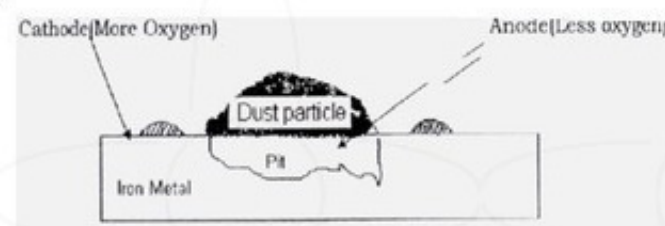
3a) i Waterline Corrosion



- Let us consider iron rod dipped in an electrolyte or water. Part of metal or iron rod con tact with less oxygen concentration acts as anode and undergoes corrosion.
- Other part of metal above water line which is ion contact with higher oxygen concentration acts as cathode and is unaffected.

Eg: Ship sailing on water, Steel water tank.

ii. Pitting Corrosion :



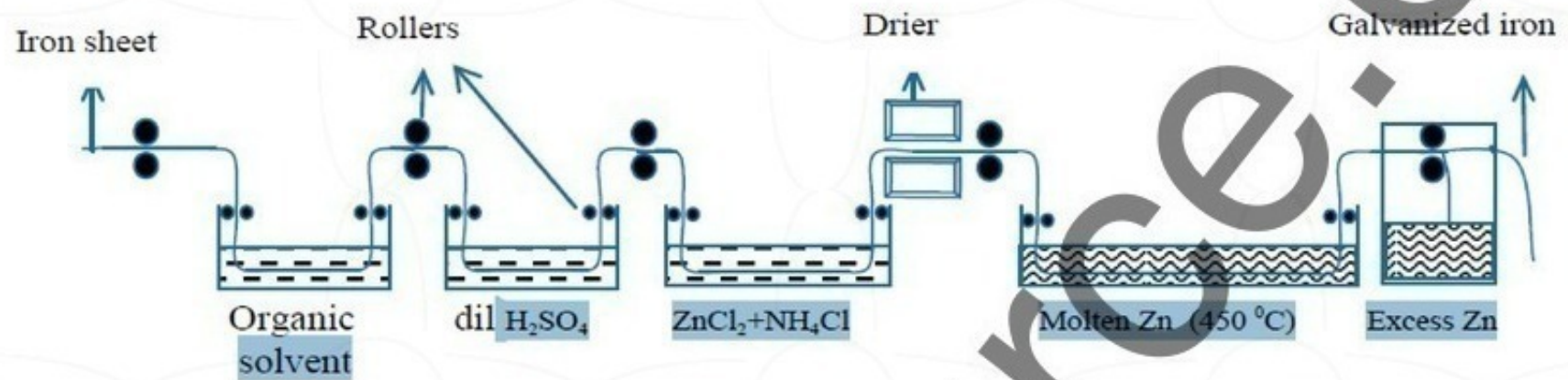
- Deposition of impurities like dust, sand, drop of oil or water on metal surface induces pitting corrosion.
- Part of metal covered by the impurities is in contact with less oxygen concentration compared to other part of metal.
- Due to this uneven oxygen concentration oxygen concentration cell is formed.
- The part of metal below the impurity which is in contact with less oxygen concentration acts as anode and undergoes protecting the other part of the metal.
- Corrosion starts just beneath dust particles resulting in formation of small hole known as pit. Since this type of corrosion results in formation of pit it is known as pitting corrosion. Once the pit is formed rate of corrosion increases.

Eg: Less aerated areas of machinery.

3b)i. Galvanization:

- The process of coating of zinc on surface of iron is known as galvanization.
- Galvanization is an example of anodic coating. The process of galvanization can be diagrammatically represented as follows:

The process of galvanization is as follows:



- Article to be galvanized is cleaned with organic solvent to remove oil, grease if present on the surface.
- Rust and other oxides are removed by treating it with $\text{dil. H}_2\text{SO}_4$.
- Finally the cleaned article is dipped in molten zinc containing ammonium chloride $[\text{NH}_4\text{Cl}]$.
- NH_4Cl prevents oxidation of zinc and acts as an accelerator. Excess of is removed by passing the articles between two rollers. Then the articles are cooled down to room temperature.
- Galvanization is safe and efficient. This is due to the factor according to which rate of corrosion is less if anodic area is large and cathodic area is small.

Applications:

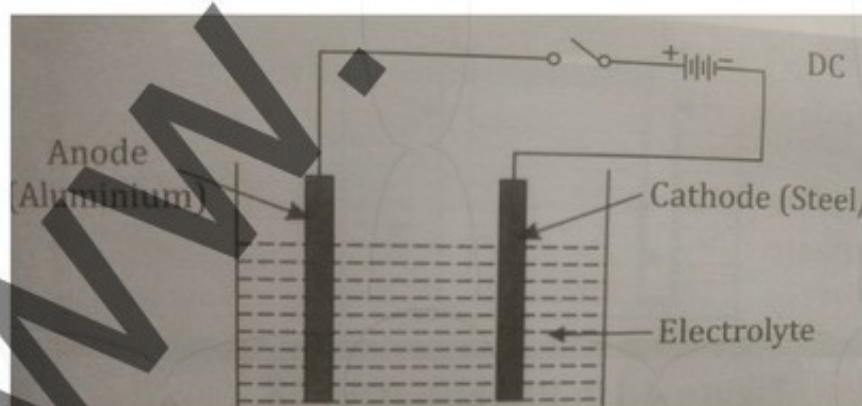
Used in protecting roofing sheets, wires, pipes, nails, bolts, buckets etc.

Used in electrical appliances.

Anodizing:

The process of increasing thickness of oxide layer on passive metals artificially in acid medium is known as anodizing.

Anodizing of Aluminium:



Aluminium articles to be anodized is degreased thoroughly, washed dried and subjected to anodizing as follows:

Anode- Aluminium

Cathode- Graphite

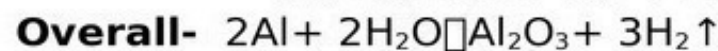
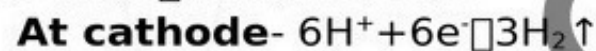
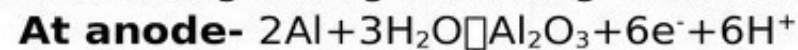
Electrolyte- Sulphuric Acid or chromic acid

Voltage- 40 volts

Temperature- 35° C

Current density- 10-20 mA/cm²

Reactions occurring during anodizing of Aluminium are:



- Anodizing of Aluminium is carried by passing DC in acid medium in which the metal is suspended.
- Oxide layer is formed due to progressive oxidation of metal. This oxide layer acts as a barrier between metal and corrosive environment thereby preventing corrosion of base metal.
- The coating found is slightly porous so it is sealed by dipping in hot water. Thickness of film can be controlled by adjusting current and bath solution.

Applications:

- Used in window frame, computer hardware and home appliances.
- Used in satellites. Due to minimum maintenance used in roofs, curtains, staircase, escalator etc. Used for office partitions, cabins etc.

3c) "The process of depositing a metal on a catalytically active substrate using reducing agent, without using electricity is known as electroless plating"

It can be represented as



Eg : Electroless plating of Cu, Ni etc

Electroless plating of Nickel :

The metallic surface to be plated is degreased and by using organic solvents or by using hot alkali treatment followed by pickling to remove scales and hardly adhered impurities. Non metallic objects are activated by dipping in SnCl₂ and then PdCl₂

Composition of plating bath :

Electrolyte solution : NiCl₂

Reducing agent : Hypophosphite

Buffer : Acetate buffer

pH : 4 - 5

Complexing agent : Sodium succinate

Temperature : 45 - 60°C

Cathode : article to be plated (pretreated)

At Anode $\text{H}_3\text{PO}_2 + \text{H}_2\text{O}$

$\text{H}_3\text{PO}_3^- + 2\text{H}^+ + 2\text{e}^-$

A Cathode $\text{Ni}^{2+} + 2\text{e}^- \rightarrow \text{Ni}$

Over all reaction $\text{H}_3\text{PO}_2 + \text{H}_2\text{O}$

$\text{H}_3\text{PO}_3^- + 2\text{H}^+ + 2\text{e}^-$

4a) The process carried out to modify surface properties of metals, alloys, plastics etc by depositing a layer of other metal, polymer or forming oxide layer is called Metal Finishing

The Technological importance of metal finishing are

- To provide Corrosion resistance
- To give decorative surface
- To provide / improve thermal & electrical conductivity
- To improve hardness
- To impart optical reflectivity
- To impart thermal resistance
- To improve hardness
- To impart wear resistance
- To impart abrasion resistance

4b) i. Polarization

Definition: Polarization is defined as "The decrease in electrode potential due to inadequate supply of metal ions from bulk of the solution to the vicinity of the electrode."

Explanation: Polarization is related to an electrode in an electrochemical cell

- The Electrode potential of a cell is determined by the following Nernst equation

$$E = E^0 + 0.0591/n \log[M^{n+}]$$
- Where $[M^{n+}]$ is the concentration of metal ions surrounding the electrode at equilibrium
- When current flows, the metal ion concentration in the vicinity of the electrode decreases due to following reaction

$$M^{n+} + ne^- \leftrightarrow M$$
- As a result of above reaction there will be decrease in electrode potential
- When ions from bulk of the solution diffuse towards the electrode equilibrium is reestablished.
- If diffusion is slow (diffusion of metal ion from bulk of solution to vicinity of electrode) the electrode is said to be polarized & the process is known as polarization

Disadvantages Of Polarization

- Polarized galvanic cell develops potential smaller than predicted
- In an electrolytic cell, polarization needs to use more negative potential than required

Polarization can be minimized by

- Increasing the temperature
- Increasing rate of stirring
- Addition of de-polarizers such as Nitric acid & Chromic acid
- Making electrode surface rough
- Using large electrode surface

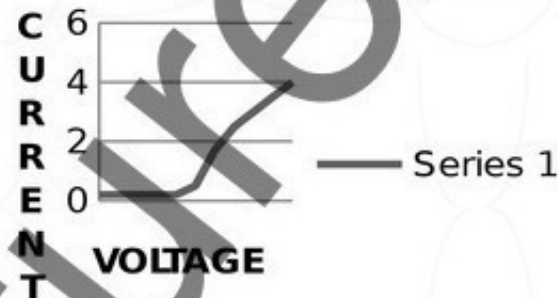
ii. Decomposition Potential

- During electrolysis process, the products accumulate on electrode surface causing change in concentration around the electrodes.
- This develops a potential which opposes the applied voltage, which is known as Back EMF

Definition: Decomposition Potential is defined as "The minimum external voltage which is applied greater than back emf in order to bring about continuous electrolysis "

Explanation: Let us consider electrolysis of an dilute acid or base using Platinum electrodes

- When an voltage is applied, at once electrolysis starts & stops very soon, this is because back emf exceeds applied voltage (due to liberation of H_2 & O_2 at electrodes)
- Now electrolysis starts only if applied voltage is increased greater than back emf
- That additional voltage greater than emf is known as Decomposition Potential
- Above explanation can be graphically represented as



iii. OVER VOLTAGE

Definition: "The voltage that has to be applied greater than theoretically determined decomposition potential in order to maintain continuous electrolysis"

Explanation: For carrying out continuous electrolysis process the applied voltage should be greater than back emf

- It is observed in few cases that electrolysis does not occur unless potential greater than theoretically determined decomposition potential is applied.
 - Ex: For electrolysis of dil. Sulphuric acid the required potential is 1.7V, but theoretically determined potential is 1.23V, therefore over voltage is 0.4V
- Factors affecting Over Voltage are
- Temperature
 - Current

- Electrode potential
- Rate of stirring

4c) Corrosion of specimen occurs due to flow of electrons from anode to cathode. The technique of protecting a specimen from corrosion by providing electrons from an external source or converting anodic sites to cathodic sites is known as cathodic protection

Sacrificial Anodic Method:

- Here metal to be protected from corrosion is converted into cathode by connecting it to a metal which is anodic to it.
- The base metals are usually Fe, Cu & brass.
- Metals like Zn and Mg which are more active than iron are used to supply electrons to the specimen thereby converting the anodic sites to cathodic sites.
- Since anode undergoes corrosion protecting the specimen is called sacrificial anodic method
- The sacrificial anodes are replaced by new ones.
- This method is used to protect ships, pipelines etc.



Eg: In case of ship Mg hull is connected to base of the ship which acts as sacrificial anode and prevents corrosion of base of the ship.

Advantages:

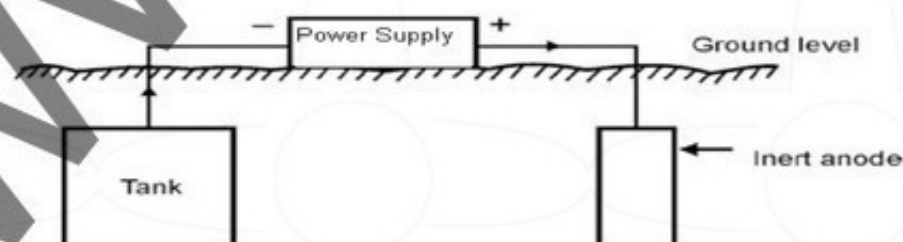
- Low installation cost
- Low maintenance
- Simple method

Disadvantages:

Involves recurring expenditure for replacement of sacrificial anodes.

ii. Impressed Voltage Method:

- It is a method of protecting base metal by applying current larger than corrosion current. In this method electrons for protection are supplied from DC power source.
- Metal to be protected is made as cathode by connecting to external power supply as shown in the figure:



- Anode is inert metal like graphite.
- The metal structure being cathode doesn't undergo corrosion.
- Hence, remains unaffected.
- This technique is used to protect water tanks, oil tanks, oil pipelines etc.

Advantages:

- Low maintenance
- One installation can protect large area of metal

Disadvantages:

Impressed current should be uniform or else localized corrosion occurs.

5a) Chemical fuels are defined as "substance which contains Carbon and Hydrogen as its main constituents and produce significant amount of heat and light on Combustion.

Fuels are mainly classified into two types :-

1) Based on physical state.

These are further classified into:-

- Solids Eg: wood, coal, charcoal, peat, lignite, bituminous etc.
- Liquids. Eg: petrol, diesel, kerosene.
- Gaseous. Eg: LPG, CNG, biogas, etc.

2) Based on occurrence

There are two types:-

- Primary fuels:
All naturally occurring fuels are known as primary fuels. Example:- wood, coal, crude petroleum oil, natural gas.
- Secondary fuels:
The products of primary fuels which can be used as fuels are known as secondary fuels. Example: charcoal, petrol, diesel, kerosene, LPG, CNG, etc.

5b) Fuel cells are galvanic cells in which Electrical energy can be obtained continuously as long as the fuels are supplied and the products are removed simultaneously.

Difference between conventional batteries and fuel cells are as follows

Conventional batteries	Fuel cells
------------------------	------------

1	Secondary batteries are rechargeable	Fuel cells are not rechargeable
2	Anodic, Cathodic components, electrolyte, separator forms the integrals parts of the batteries	There is a continuous movement of fuel and oxidant in and out of the cell
3	Battery stores Chemical energy	Fc's do not store any chemical energies
4	Low efficiency of production of electrical energy	High efficiency of production of electrical energy

Advantages of fuel cells:

- 1 • Power output is high.
- 2 • Do not pollute the atmosphere
- 3 • Electrical energy can be obtained continuously

Disadvantages of Fuel Cells

- High pressure should be maintained
- Reactants should be supplied continuously.

5c) Solar Grade Si is obtained by 2 steps

I. Manufacture of Metallurgical Grade Si

Al . Conversion Of Metallurgical Grade Si in Solar Grade Si

Step I: Manufacture of Metallurgical Grade Si

Silica(SiO_2) is reduced to silicon (Si) by heating it with carbon in an electric arc furnace and heated to $1500-2000^\circ\text{C}$.



Silicon obtained above is treated with air and fresh silica as a flux to remove the impurities Al, Mg and Ca

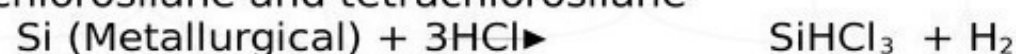


Oxides of Al, Mg and Ca form insoluble slag with excess of silica which is separated from molten silica. And silica obtained above is called metallurgical grade Si (98 %)

StepII: Conversion Of Metallurgical Grade Si in Solar Grade Si

Solar grade is obtained in following steps

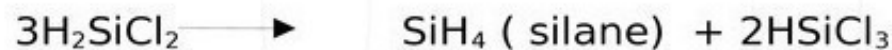
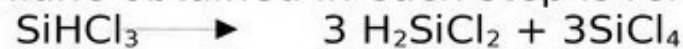
1. Metallurgical grade silicon is refined by heating it with anhydrous HCl at 300°C to obtain trichlorosilane and tetrachlorosilane





2. Trichlorosilane is separated by distillation and tetrachlorosilane is converted into trichlorosilane by hydrogenating in a reactor at 1000°C
- $$\text{SiCl}_4 + \text{H}_2 \rightarrow \text{SiHCl}_3 + \text{HCl}$$

3. Trichlorosilane is converted into silane by passing through fixed bed columns containing quaternary ammonium ion exchange resin as catalyst. Silane obtained in each step is removed by distillation.



Tetrachlorosilane and trichlorosilane obtained in the above steps are again passed through reactor and fixed bed columns respectively and finally converted to silane.

Pyrolysis: Silane obtained in the above step is subjected to pyrolysis in a reactor at high temperature. In pyrolysis reactor, pure silicon rods are used for heating. Si formed by decomposition of silane gets deposited over these pure Si rods.



Si thus obtained is known as Solar Grade Silicon & can be further purified by zone refining.

6a) A PV cell is a semiconductor device that converts photons from the sun into electricity.

Advantages

- They are Eco-friendly.
- They do not corrode
- They do not contain any moving parts
- Recharging is not required
- Its economical

Disadvantages

- Not available during night. (Complicated to store the energy)
- Very expensive and installation cost is very high.
- PV cells generate only DC current.
- Unavailable during monsoon.
- Usage of cadmium in certain types of cells

6c) Power Alcohol

- When ethanol is mixed with petrol and is used as fuel is known as power alcohol.
- Nearly 25% of ethanol is mixed with petrol to get power alcohol.
- Alcohol and petrol are two immiscible liquids and hence blending agents such as C_6H_6 , ether, etc. are added.

Advantages of power alcohols

- Octane rating of power alcohol is high.
- It has less knocking tendency.
- Alcohol promotes more complete combustion.
- Power output of alcohol is high compared to gasoline or petrol.
- Alcohol present absorbs moisture if in present in petrol

Unleaded petrol: The gasoline which does not contain any lead compound is called unleaded petrol. In addition to it, compounds like Methyl tertiary butyl ether (MTBE) or Ethyl tertiary butyl ether (ETBE) is added to improve octane number of unleaded petrol in IC engines, thereby reducing considerably the formation of peroxy compounds

7a) Sources: Discarded computers, televisions, VCRs, stereos, copiers, fax machines, electric lamps, cell phones, audio equipment and batteries

Effects: If improperly disposed can penetrates into soil and groundwater & are threat to human health and environment.

Disposal Methods

- 1 Landfilling
Tranches are made for burying the e-waste in the soil. Landfill is not an environmentally friendly process for disposing e-waste as toxic substances like Cd, Pb & Hg are released inside the soil & ground water.
- 2 Recycling of e-waste.
Mobiles, Monitors, CPU's, Laptops, keyboards, connecting wires & cables can be reutilized with the help of recycling process. Recycling process involves dismantling of electronic evices, separation of the parts having hazardous substances & then recovery of precious metals like Cu, Au etc with the help of e-waste recycler.
- 3 Reuse of Electronic Devices.
Mobiles, laptops, printers etc., with slight modifications can be used or sold as second hand product. The old electronic equipment can also be donated in the various charity programs & thus helping the persons in need.

7b) Sources: Thermometers, Mercury Vapour Lamp, Batteries

Effects: Mercury can result in complex neurological problems, especially in young children and babies, which affect the brain and nervous system, potentially leading to cerebral palsy, delayed onset of walking or talking, learning disabilities.

Control: Mercury and Lead can be controlled by dumping properly lead batteries and mercury lamps at proper place

9a) Principle: When a solution having a mixture of metallic species is introduced into the flame, the solvent evaporates and vapour of metallic species is obtained. Some of metal atoms can be raised to an energy level sufficiently high to emit characteristics radiation of metal—a phenomenon that is used in flame photometry. Here a large amount of metal atoms remain in non-emitting ground state. These ground state atoms of a particular element are receptive of light radiation of their own specific resonance wavelength. In this way, when a light of this wavelength passes through a flame, a part of light will be absorbed and this absorption will be proportional to the intensity of atoms in the flame. So in atomic absorption spectroscopy the amount of light absorbed is determined because the absorption is proportional to the concentration of the element.

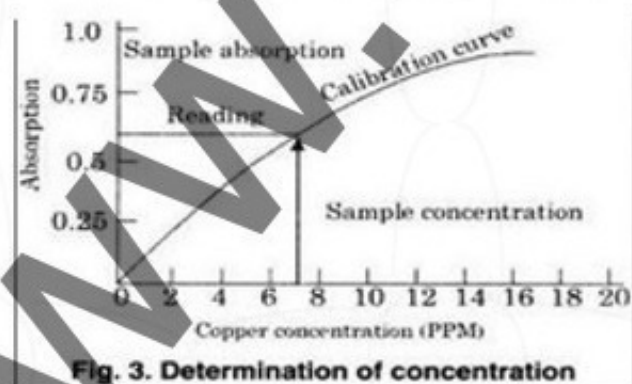
The apparatus consist of:

(1) Radiant Source (2) Atomizer (3) Mono chromator (4) Lenses and Slits and (5) Detectors.

The main components used in the instrument can be described as follows:

- 1 Radiant Sources:** Generally a hydrogen lamp is used as continuous source of radiation.
- 2 Atomizer:** Generally burners are used to break the liquid sample into droplets which are then allowed to enter into flame. The droplets are then evaporated and sample element is left in residue. The residue is then decomposed by flame. Thus in this process the sample is reduced to atoms.
- 3 Hollow Cathode Lamp:** These gases emit sharp line spectra. Generally these lamps are constructed for individual elements but multi-element lamps have also been prepared for all purposes. The hydrogen lamp is a hollow cathode lamp. A hollow cathode lamp emits more than one composite line for each element but the required spectral line can be separated by means of a relatively low dispersion monochromator. Most of lines are non-absorbing lines because they involve transition other than from ground state. The most intense absorption line is selected to provide maximum intensity.
- 4 Monochromatic:** Generally the mono chromators are gratings and prisms.
- 5 Filters or slits:** Filters or slits are used for isolation of required spectral line if element has a simple line spectrum. Filter photometers are used for determination of potassium, sodium calcium, magnesium etc. in samples.
- 6 Detectors:** Generally photomultipliers are used as detectors. In some instruments two filters and two detectors are used to compensate the fluctuation in the sources.

Procedure: First of all, a meter is adjusted to read zero absorbance or 100% transmittance when a blank solution is sprayed into the flame and light of hollow cathode lamp passes on to photomultiplier tube. Now the solution to be investigated is introduced, a certain part of light is absorbed resulting in decrease of light intensity falling on photomultiplier. This gives a deflection in the meter needle which is noted immediately. As this is a comparative method hence standard solutions of elements are used to make a calibration curve from which the concentration of sample elements can be calculate



Applications of Atomic Absorption Spectroscopy:

Quantitative Analysis

Disadvantages of Atomic Absorption Spectroscopy:

1 This technique has not proved very successful for the estimation of elements like V, Si, Mo, Ti and Al because these elements give oxides in the flame.

2 In aqueous solution, the anion affects the signal to a noticeable degree.

3 A separate lamp is needed for the determination of each element. Attempts are being made to overcome this difficulty by using a continuous source.

9c) Following steps involved in the synthesis: a) Preparation of sol, b) Conversion of sol to gel, c) Aging of a gel, d) Removal of solvent and e) Heat treatment.

Inorganic salt is dissolved in water or suitable solvent to make a homogeneous solution.

The homogeneous solution is hydrolyzed using water in the presence of acid or base and converted into sol

Gel is obtained by condensing the dispersed colloidal particles in the sol. Gel is an interconnected rigid and porous inorganic network enclosing a continuous phase. This transition is called sol-gel transition.

The polycondensation reaction continues until the gel transforms into a solid mass of nano scale clusters accompanied by contraction of the gel network and expulsion of solvent from gel pores. The aging process can exceed 7 days and is critical to the prevention of cracks in the gel that have been cast.

The encapsulated liquid is removed from the gel by evaporative drying.

The sample thus obtained is heat treated to obtain nanoparticles.

Ex: **CdSe semiconductor nanocrystals** are obtained by Sol –Gel method. A solution of dimethyl cadmium, a surfactant and tributylphosphineselenide is heated to 300 °C with continuous stirring. CdSe nanoparticles nucleate rapidly and then grow in size to become nanocrystals. The product is capped with surfactant, filtered and washed with acetone to remove the impurities.

Advantages;

Nanomaterials of high purity with good homogeneity can be obtained

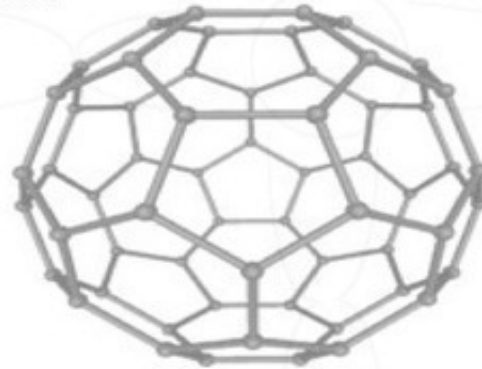
Samples can be prepared at lower temperatures

Shape and size of the materials can be controlled.

10a) **Fullerene** is a pure carbon molecule composed of at least 60 atoms of carbon, arranged as 12 pentagons and 20 hexagons. The diameter of the molecule is 1 nm. It is composed of carbon in the form of a hollow sphere, ellipsoid, tube, and many other shapes. Spherical fullerenes are also called **buckyballs**, and they resemble the balls used in football (soccer).

Cylindrical ones are called carbon nanotubes or buckytubes. Fullerenes are similar in structure to graphite, which is composed of stacked graphene sheets of linked hexagonal rings; but they may also contain pentagonal (or sometimes heptagonal) rings. The first fullerene molecule was named as buckminsterfullerene (C_{60}), as a homage to Buckminster Fuller

Fullerene structure is as follows.



Applications;

It is used in electrographic imaging, solar cells, nonlinear optical thin films, magneto optical recording etc.,

It is used in making carbon films, tunnel diodes, photolithography and double layer capacitor and storage devices

It is widely used for the conversion of diamond.

In the separation of chromatography materials, absorbent for gases etc.

It is used in gas sensors, temperature sensor, particle sensors and in detection of organic vapours.

Used as lubricants, adhesives, charge transfer complexes, cosmetics, catalysts.

It is used in secondary batteries, non aqueous batteries and fuel cell electrodes.

10b) Nano materials are the physical substances with at least one characteristic dimension between 1-150 nm. A nanometer (nm) is one billionth of meter or 10^{-9} m.

In chemical Vapour condensation method reactant gases (precursors) are pumped in to a reaction chamber (reactor). Under the right conditions (T, P), they undergo a reaction at the substrate. One of the products of the reaction gets deposited on the substrate. The by-products are pumped out. The key parameters are chemical (reaction rates, gas transport, diffusion).

Ex: GaAs semiconductor nanoparticles are synthesized by chemical vapour deposition method from organometallic precursors. Trimethyl gallium and AsH_3 are used as precursors and hydrogen is used as a carrier gas as well as reducing agent. Reaction occurs at the

temperature of 700 °C at atmospheric pressure. GaAs nanoparticles are collected on a porous film downstream at a temperature of 350 °C. The product obtained is sized single crystal GaAs with diameters ranging from 10 to 20 nm. The byproduct gas is easily removed out of reactor by carrier gas.

Advantages:

- Simple technique and does not require ultrahigh vacuum
- Possible to deposit nanomaterials with almost any shape and any size
- Byproducts and leftovers are easily removed.

Disadvantages

Precursors used are volatile, and usually hazardous and extremely toxic. The byproducts are also toxic.